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UPON THE MAGNETIC SEPARATION OF THE LINES OF BARIUM, YTTRIUM, ZIRCONIUM, AND OSMIUM

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I. INTRODUCTION

The investigations of Balmer,[1] followed by Rydberg[2] and by Kayser and Runge,[3] showed that many of the spectral lines of different substances formed series, which could be expressed by a simple empirical equation. Preston,[4] in the study of the Zeeman effect, observed that similar series for different substances had identical magnetic separation of the lines, when these separations were measured in wave frequencies instead of wave-lengths. Preston's data were very meager and his law was first thoroughly established by Runge and Paschen.[5] Inversely then lines of like magnetic separation are members of a series, according to Preston's law, and therefore

[1] *Wied. Ann.*, **25**, 80, 1885.

[2] *Phil. Mag.*, (5), **29**, 331, 1890; *Zeit. Phys. Chem.*, **5**, 227, 1890; *C. R.*, **110**, 394, 1890; *Kgl. Svenska Vet. Akad. Handl.*, **32**, Nr. 11, 1890; *Astrophysical Journal*, **6**, 239 and 338, 1897.

[3] C. Runge, *Report Brit. Assoc.*, 1888, pp. 576, 577; Kayser and Runge, *Wied. Ann.*, **41**, 302, 1890; **43**, 385, 1891; **48**, 126, 1893; **52**, 93, 1894; Runge and Paschen, *Berl. Ber.*, 1895, 639, 759; *Astrophysical Journal*, **3**, 4, 1896; *Wied. Ann.*, **61**, 641, 1897; *Astrophysical Journal*, **8**, 70, 1898.

[4] *Phil. Mag.*, (5), **45**, 325, 1898; *Proc. Royal Dub. Soc.*, **6**, 385, 1898; *ibid.*, **7**, Part II, p. 2.

[5] *Sitzungsber. der Berl. Akad.* am 6. Feb., 1902; *ibid.*, **19**, 380, 720, 1902; *ibid.* (Runge and Precht), **10**, 417, 1904; *Astrophysical Journal*, **15**, 235, 333, 1902; *ibid.*, **16**, 123, 1902.

the magnetic separation may be used to establish series. In fact, Runge suggested this possibility, and applied it to barium where no series had been discovered. He found that barium gave representatives of series, but not in sufficient number to establish the series.

The following experiments propose to use this inverse method, first in a more complete study of barium, and then in other substances wherein no series have been found, to see whether a series relationship can be established in any of the different types of magnetic separation.

II. EXPERIMENTAL METHOD

The spectral lines were photographed by means of a 21-foot concave grating with a fixed circular camera. The light consisted of a spark of the substance which had been dried upon thin carbon plates and so placed in a strong magnetic field that the spark was parallel to the lines of force.[1] Owing to the varying intensity of the different lines photographs were taken with different lengths of exposure, varying from fifteen minutes to two hours in the violet up to six hours in the red. The photographs were all taken with the pole pieces at the same distance apart, so that by varying the current on the electromagnetic circuit one could obtain *ad libitum* any field-strength up to the maximum of 24,400 lines per sq. cm. The field-strength was determined by repeated measurements of the separation of the calcium line 3968.6, which occurs on account of an impurity in the carbon electrode, and by a few special photographs of the zinc line 4680, assuming Runge's measurements for these lines at 31,000 C. G. S. units to be correct. All calculations are given at the above maximum field-strength. Other field-strengths were used to determine the true components of lines very close together or to obtain readings for overlapping components. Frequently such lines are determined from the distance of the one free component from the undisturbed position. Photographs of vibrations parallel to the lines of force were taken upon one set of plates, and perpendicular to the lines of force upon another set of plates. This was effected in the usual way by means of a calcite prism. Photographs taken without the calcite, i. e., with both the parallel and perpendicular components on one set of plates,

[1] Many substances adhere so well to carbon that the writer thinks this plan, together with the circular camera, will make it possible to photograph some of the promising costly substances.

were used only to obtain the relative intensity of the parallel and perpendicular components. In these photographs the parallel and perpendicular components often are so close to each other as to prohibit their separation, and thus preclude any knowledge of their respective intensities. In triplets of large separation, however, it was a matter of no difficulty. By a double comparison of such lines with corresponding components on parallel and perpendicular plates, the ratio of the intensities of the parallel and perpendicular plates is established. The lines may then be compared on perpendicular and parallel plates, although the conditions of exposure and development may have been quite different. But withal there is a chance for a very large error in intensities, since there is a wide range in width and depth of the shadows, and no experimental method is employed to compare the intensities of the shadows, as is done in photometry and spectro-photometry.

The variation in actinic sensibility of the plates throughout the spectrum is enormous, so that one must resort to differently prepared plates. Furthermore, the red sensitive plates, self-prepared with dicyanin, were far from uniform. Hence, a comparison of intensities of different lines, which is very important in investigation for series, can be roughly accurate only within a short spectral range. This is generally sufficient to show that two, or more, near lines of like magnetic separation, but of great inequality in intensity, do not belong to the same series. This is all that should be expected from the intensities given in the following experiments. How great the variations in intensities may be under the different conditions of experiment may be seen by comparing the intensities here recorded with those given in Exner and Haschek's tables, which have been freely used. There is enough similarity in intensities to make their tables serviceable for the identification of lines.

Intensities are recorded for the components of the first-order lines, whether the lines were measured in first or second order. The lowest intensity 1 is just observable. It is measurable only when very favorably located in a group of components and then with no special accuracy. A line of intensity 2 is capable of fair measurement in groups of several components, but is not satisfactory in a doublet of broad separation. Intensity 3 is the lowest intensity satisfactory

under the latter conditions. Diffuse lines of higher intensities may also be unsatisfactory. A pair of components which are diffuse outward or inward indicates the presence of outer or inner weak components, which may be brought out when self-induction, capacity, slit-width, and exposure of plates have been properly balanced. Broad single lines suggest a similar possible resolution. Hence a record of these facts may be helpful, even if the resolution has not been effected. The accuracy of the readings also depends upon the sharpness of the lines. Where weakness, diffusion, or presence of overlapping components has made a reading less accurate, the result is tabulated in brackets. The bracketed values are still close enough to give a reasonable idea of the magnitude of the separation. Overlapping components can usually be circumvented by varying the field-strength. However, this did not always suffice, and it was necessary to omit an occasional component in a line, e. g., the outer violet component of zirconium 3573.3. There is large variation in definition among the lines of a substance. This is particularly noticeable in barium. The lines of osmium are uniformly exceptionally sharp, so that the readings in the latter possess nearly three times the accuracy of the former. Yttrium and zirconium occupy an intermediate position. The separations are determined from five readings for each component. These were all repeated and in most cases the repeated readings were upon other sets of plates. If the repeated readings showed an unwarranted deviation from the old result, the line was subjected to further analysis upon both plates. In zirconium there is certainly an error of 0.005 mm possible. Cases of double the magnitude may have escaped my attention but such cases are few. This value gives a minimum error in $\Delta\lambda/\lambda^2$ in the second order at 4500 of 0.025, and a maximum error in the first order at 3250 of 0.09. Hence it is desirable as far as possible to limit the readings in the shorter wave-lengths to the second order photographs.

The identification of the lines in the violet and ultra-violet spectra was made by the Exner-Haschek spark-spectrum tables, which generally proved very satisfactory. An occasional difficulty was met. For example, in zirconium a very well-defined line of eight components was found at about 4214 which failed to identify with impurities or with zirconium 4214.58. It does, however, identify with the arc

light table line 4214.05. Such a difference in arc-line wave-length and spark-line wave-length is very exceptional, but in the absence of line 4214.58, it indicates that the line in question is the same. Rough measurements frequently gave readings closer to the arc-light lines than the spark lines, and many such might have been detected had very careful comparator measurements of distances from line to line been made. Sometimes such comparator measurements are necessary in identification as it may be a required line or impurity. Difficulty was encountered in three lines toward the red of 3392.20. These three lines measured from 3392.20 gave 3393.36 instead of 3393.30; 3394.96 instead of 3394.79, or possibly this is another line; and 3396.87 instead of 3396.71. A fourth line 3396.49 is certainly in close enough agreement with 3396.51. Several other lines appeared which have not been identified.

III. EXPLANATION OF TABLES

The abbreviations in the tables have the following significance, viz.: λ, wave-length; $\Delta\lambda/\lambda^2$, the change in vibration per cm; *s*, vibrations perpendicular to the lines of force, and *p*, parallel to the same; H, principal series; G, greater wave-length; K, smaller wave-length; N, subordinate series; S, satellite; *h*, principal line; R, observations according to Runge; M, observations according to Moore; *i*, intensity. Column A gives the approximate value of the components represented in terms of a small separation, called the "interval," multiplied by small numbers called "factors." The factors represent the ratio of the distances of the successive components from the position of the undisturbed line. Column B gives remarks. Inasmuch as duplicate remarks frequently occur, they have been designated by the following abbreviations, viz.: D, diffuse; D_r, diffuse toward the red; D_b, diffuse toward the blue; D_i and D_o, diffuse inward and outward respectively, which generally suggests the presence of interior and exterior weak components respectively; *w*, slightly broadened; *b*, much broadened; b_o and r_o, blue and red components respectively, overlapped by component of an adjacent or foreign line; n. i., not identified, i. e., the line does not compare with any line in Exner and Haschek's tables. Special remarks are indicated by numbers which are explained at the foot of their respective tables. In the

quadruplet tables the *s*- and *p*-components are each designated by a double sign ($\mp$) to avoid repetition. The *s*-component is recorded first. The double sign therefore means two readings. The triplet *s*-components are similarly designated and the *p*-component is omitted. Two intensities are frequently given in the triplets. The first recorded value then represents the *s*-component and the second the *p*-component. When there are three intensities for triplets, the outer *s*-components are unequally intense. The first reading is then the red and the third the blue component. When only one intensity under triplets is given it refers to the *s*-component and the *p*-component has twice the intensity.

IV. BARIUM

The barium lines for wave-lengths shorter than 5854 were measured from plates exposed by Professor Runge. Much time was spent in trying to obtain stronger photographs of barium to bring out the weaker lines. These lines were either not upon the new plates or too diffuse for satisfactory measurements. A few of the sharpest lines of the new plates were measured and found in agreement with measurements made from Professor Runge's other lines. These observations and those by Professor Runge upon barium I have reduced to the field-strength, 24,400 C. G. S., used in all subsequent measurements. The photograph of the red spectrum yielded all lines but two in Kayser and Runge's arc spectrum, and several new lines, most of which are weak. The wave-lengths of these lines are determined from their distances from lines already known and the Ångström scale values determined from known second-order iron lines. Constant use of this iron calibration with zirconium and yttrium lines, along with Exner and Haschek's tables, leads me to think that the new wave-lengths may be relied upon to within 0.1 Angström unit. The intensities for the red spectrum are given, and show the comparative intensities for that part of the spectrum. When one value only for intensity is given it refers to the perpendicular component, and the omitted parallel component has about double the intensity. Exceptions to this are noted under some lines.

In Table *Ba*$_1$ are given the values of $\Delta\lambda/\lambda^2$ for lines observed by Runge and Paschen and remeasured by the author for a comparison

of the accuracy obtainable. Barium has been found the poorest substance of the four studied for such a comparison.

TABLE Ba_1

H. G. λ 4934		2 N. K. λ 4525		2 N. G. λ 4900		H. K. λ 4554		I. N. K. λ 5854		I. N. S. λ 4166	
R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.
−1.44	−1.45	−1.42	−1.44	−1.75	−1.83	−1.75	−1.83	−1.76	−1.76	−1.63	....
−0.74	−0.72	−0.76	−0.72	−1.09	−1.11	−1.08	−1.11	−1.19	−1.19	−1.16	....
+0.73	+0.71	+0.75	+0.74	−0.36	−0.35	−0.36	−0.35	−0.92	....	−0.88	−0.87
+1.45	+1.46	+1.45	+1.44	+0.35	+0.37	+0.35	+0.37	+0.58	−0.58	−0.62	....
				+1.07	+1.11	+1.06	+1.10	+0.58	+0.57	+0.55	....
				+1.75	+1.80	+1.79	+1.82	+0.91	....	+0.90	+0.87
								+1.19	+1.16	+1.14	....
								+1.76	+1.74	+1.70	....

In Table Ba_2, the line 6675.3 has its components in the ratio of ± .635 (0, 1, 3); the line 5997.4 may be represented by ± .55 (1, 2, 3); the line 5971.9 by ± .30 (2, 5); and the line 4580 possibly by ± .10 (4, 8, 15).

TABLE Ba_2

λ 6675.3			λ 5997.4			λ 5971.9			λ 4580		
i	Δλ/λ² *		*i*	Δλ/λ²		*i*	Δλ/λ² †		*i*	Δλ/λ²	
5	−1.90	*s*	3	−1.64	*s*	8	−1.49	*s*		−1.54	*s*
1	−(0.64)	*p*	6	−1.10	*p*	10	−0.61	*p*		−0.81	*p*
1	0.00	*p*	3	−0.56	*s*	10	+0.60	*p*		−0.38	*s*
1	+(0.63)	*p*	3	+0.54	*s*	8	+1.49	*s*		+0.39	*s*
5	+1.90	*s*	6	+1.10	*p*					+0.81	*p*
			3	+1.66	*s*					+1.46	*s*

* The *s*-component of 6451 agrees with this, and possibly the parallel components, as the latter appears a broad weak band, rather than a single line.

† The *s*-components are broad and may resolve into two lines each. They are strongest at center. This is not usually the case with lines which resolve with better definition.

Table Ba_3 contains a list of triplets arranged in groups with like separation. The omitted parallel component is in the position of the line without field, i. e., with zero separation. Groups I, III, and IV stand in the simple ratio of 3 : 2 : 1. The separation in Group II differs from Group III by 1/11. The separation in Group III Professor Runge has designated the normal triplet "*a*" (see later in VIII, "Comparison of Substances"); or these groups are $3a/2$, a, $a/2$, and $12a/11$. Groups I, III, IV are represented in one single line 5997.4 excepting the zero component. Group I is also represented in 4166, Group II in 5854, and Group III also in 4554. In Table Ba_4 are the remaining lines of barium and under remarks are indicated

TABLE Ba_3

Group I			Group II		
λ	i	$\Delta\lambda/\lambda^2$	λ	i	$\Delta\lambda/\lambda^2$
6694.4*	5	∓1.66	6527.6†	12	∓1.24
6341.9	8	1.59	6148.6	3	1.17
4692.0		1.65	6141.9	30	1.20
4574.0		1.64	5778.0		1.22
4506.0		1.67	4416.0		1.18
4432.0		1.64	4131.0		1.18R
4414.0		1.62			1.18M
3889.4		1.68	3993.0†		1.24
			3071.7		1.17

Group III			Group IV		
λ	i	$\Delta\lambda/\lambda^2$	λ	i	$\Delta\lambda/\lambda^2$
6483.1	8	1.14	6653.7	4	0.55
6182.6	2	1.08	6611.8	8	0.56
6165.4†	2	1.06	6433.5	6	0.57
6063.3	12	1.10	6019.7	10	0.555
5988.1		1.09	4132.6		0.56
5826.0		1.12			
5536.0		1.11			
4727.0		1.11			
4283.0		1.07			
3935.0		1.09			
3501.0		1.11			

* The s-components are each nearly twice as strong as the p-components. In the other lines, the parallel components are the stronger.

† May possibly not belong in this group.

lines of several components which have the value of the triplet. It will be seen from these tables that the triplets look like lines of several components with some components suppressed. Or, what is more significant, the magnitude of the separations reduce to a few in number and recur in different types of separation. Runge has noted a vibration-difference per cm of 1691 in two pairs of lines. These pairs are 4166.24 and 3891.97; and 6497.07 and 5853.9. The longer wave-length of the first pair corresponds to the satellites of the first subordinate series, and the remaining line to the same series of shorter wave-length. In the second pair of lines the shorter wave-length is the satellite. The longer wave was not measured. The measurements here gave a value of ± 0.93 for $\Delta\lambda/\lambda^2$, which is closer to the triplet value ± 0.915 of the first adjacent series shorter wave-length than the value ± 0.87 for λ 3892. The line λ 6487.7 possesses the

TABLE Ba_4

λ	i	$\Delta\lambda/\lambda^2$	Remarks
6687.5			Triplet. Too weak
6630.5			Triplet. Too weak
6595.55*	10	∓0.635	Compare 5854
6548.3	2	0.63	Compare 5854. Not *Cu* 3274.1 whose separation = 1.50
6498.9	8	1.48	
6497.1	20	0.93	
6495.3	2	0.68	Not *Cu* 3247.66 whose separation = 1.10
6484.7*	6	0.93	Not *Yt* 3242.43 whose separation = 1.33
6451.0†	3	1.89	
6435.2	4	1.29	$8a/7$?
6409.3	6		Broad. Not apparently separated
6403.1	4	0.84	
6398.84			Broad in appearance. Like several comp.
6200.3			Triplet. Too weak
6192.1	3	0.89	Compare 5854
6132.2	3	0.88	Compare 5854
6111.0	10	1.28	$8a/7$?
5519.0		1.02	
4600.0		1.53	Compare 4580
4403.0		1.28	
4350.0		1.83	Compare 4554
3996.0		1.38	
3910.0		0.84	
3892.0		0.87	

* The s-component is approximately double the intensity of the p-component.

† See footnote * to Table Ba_1.

same separation as λ 6497.1 but is characterized by having the perpendicular components much stronger than the parallel. The separation of the triplet lines in Group II is the same as the separation of the middle line of the first adjacent series.

V. YTTRIUM

λ 3818.49			λ 4235.89		
i	$\Delta\lambda/\lambda^2$	A	i	$\Delta\lambda/\lambda^2$	A
2.....	−1.74 *s*	4×0.433	2.....	−(1.26) *s*	7×0.18
4.....	−1.29 *s*	3	2.....	−(0.89) *s*	5
10.....	−0.88 *p*	2	6.....	0.71 *p*	4
3.....	−0.85 *s*	2	2.....	−(0.54) *s*	3
2.....	−0.44 *p*	1	2.....	− 0.36 *p*	2
2.....	−0.42 *s*	1	2.....	+ 0.36 *p*	
2.....	+1.42 *s*		.....	.....	
2.....	+0.43 *p*		6.....	+ 0.71 *p*	
3.....	+0.84 *s*		.....	.....	
10.....	+0.88 *p*		.....	.....	b_o
3.....	+1.33 *s*				
2.....	+1.74 *s*				

The two lines on the preceding page have twelve and ten components respectively.

The following five lines have nine components each:

λ 4398.21			λ 4199.46		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
1+.....	−(1.72) *s*	9×0.19	6.....	−2.73 *s*	5×0.54
2.....	− 1.33 *s*	7	3.....	−1.58 *s*	3
6.....	+ 0.95 *s*	5	6.....	−1.02 *p*	2
4.....	− 0.38 *p*	2	1+.....	−0.34 *s*	1
6.....	0.00 *p*	0	10.....	0.00 *p*	0
4.....	+ 0.38 *p*		1+.....	+0.58 *s*	
6.....	+ 0.95 *s*		6.....	+1.02 *p*	
2.....	+ 1.34 *s*		3.....	+1.61 *s*	
1.....	..... *s*		6.....	+2.73 *s*	

λ 3950.51			λ 3628.89		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
8.....	−1.51 *s*	3×0.50	10.....	−1.92 *s*	3×0.63
4.....	−0.98 *s*	2	5.....	−1.27 *s*	2
20.....	−0.51 *p*	1	8.....	−0.66 *p*	1
2.....	−0.49 *s*	1	2.....	−0.64 *s*	1
15.....	0.00	0	10.....	0.00 *p*	0
2.....	+0.49 *s*		2.....	+0.62 *s*	
20.....	+0.49 *p*		8.....	+0.66 *p*	
4.....	+1.02 *s*		5.....	+1.28 *s*	
8.....	+1.51 *s*		10.....	+1.92 *s*	

λ 3584.71		
i	Δλ/λ²	A
12.....	−2.07 *s*	8×0.265
6.....	−1.32 *s*	5
10.....	−0.76 *p*	3
3.....	−0.55 *s*	2
15.....	0.00 *p*	0
3.....	+0.53 *s*	
10.....	+0.74 *p*	
6.....	+1.31 *s*	
12.....	+2.07 *s*	

At λ 4398.21 a common difference between components of the value 0.38 occurs six times. The interval in λ 4199.46 seems twice the interval in 3584.71, or the two lines may both have the smaller interval in different proportions. In each of the lines 3950.51 and 3628.89, there is a case of the *s*- and *p*-components occupying the same position.

The two following lines have eight components each:

λ 4236.10			λ 4083.89		
i	$-\Delta\lambda/\lambda^2$	A	*i*	$-\Delta\lambda/\lambda^2$	A
6.....	−1.96 *s*	9×0.22	2.....	(−1.79) *s*	9×0.20
2.....	−1.53 *s*	7	3.....	−1.119 *s*	6
3.....	−0.65 *p*	3	6.....	−0.83 *p*	4
3.....	−0.22 *p*	1	1+.....	−0.64 *s*	2
3.....	+.... *p*		2.....	+0.62 *s*	
3.....	+.... *p*		6.....	+0.83 *p*	
2.....	+1.53 *s*		3.....	+1.19 *s*	
6.....	+1.96 *s*		1+.....	(+1.75) *s*	

The three following lines are sextets:

λ 4358.91			λ 3747.70		
i	$-\Delta\lambda/\lambda^2$	A	*i*	$-\Delta\lambda/\lambda^2$	A
12.....	−1.65 *s*	3×0.553	6.....	−1.04 *s*	2×0.553
15.....	−1.10 *p*	2	6.....	−0.52 *s*	1
1.....	−0.54 *s*	1	12.....	−0.46 *p*	
1.....	+0.54 *s*		12.....	+0.46 *p*	
15.....	+1.10 *p*		6.....	+0.52 *s*	
12.....	+1.65 *s*		6.....	+1.04 *s*	

λ 3195.80		
i	$-\Delta\lambda/\lambda^2$	A
8.....	−1.69 *s*	3×0.553
12.....	−1.11 *p*	2
8.....	−0.55 *s*	1
8.....	+0.55 *s*	
12.....	+1.11 *p*	
8.....	+1.69 *p*	

Here are two lines, 4358.91 and 3195.80, accurate duplicates of each other—just the kind of agreement one would anticipate in the terms of a series. Unfortunately no other terms are present within the limits of observations. The *s*-components are of equal intensity and equidistant. They are removed from the null position one and three times the value ∓ 0.55. The *p*-components are twofold the same value.

In λ3747.70, the *s*-components are one and two times the value 0.52. Direct comparison of the *p*- and *s*-plates shows that the meas-

ured difference of the *p*-components and the inner *s*-components is actually present and not an error of observation. The law of multiple relationship mentioned on pp. 5 and 30 still holds for all components, if one goes so far as to take the small difference between these *p*- and inner *s*-components as a unit. The terms are then 7, 8, and 16 times the value ∓ 0.065.

The two following quintets could not be measured accurately:

λ 4477.1			λ 3951.76		
i	$\Delta\lambda/\lambda^2$	A	*i*	$\Delta\lambda/\lambda^2$	A
2.....	−1.89 *s*	5×0.38	6.....	− 1.47 *s*	4×0.38
.....	..... *p*		1+.....	− (.383) *p*	1
.....	..... *p*		2.....	0.00 *p*	0
.....	..... *p*		1+.....	+ (.377) *p*	
2.....	+1.89 *s*		6.....	+ 1.47 *s*	

These *p*-components are not separated in the first-order spectrum. As near as could be seen in the second-order spectrum, they are the same for both lines, and may be represented by 0 and 1 times the value ± 0.38. The perpendicular components of λ 4477.10 are 5 times this value, and in λ 3951.76 they are 4 times it. The *s*-components of λ 3951.76 are diffuse inward, and suggest a pair of lines of value $\Delta\lambda/\lambda^2 = \pm 1.30$ which corresponds to a seven-fold multiple of 0.19. This only means a doubling of all the previous multiple factors.

The fourteen lines in the table on p. 13 are quadruplets. The line λ 4477.59 is an apparent quadruplet also, but too weak and diffuse to measure.

The lines λ 4475.90 and λ 3448.98 are very similar but do not belong to the same series, inasmuch as the blue line is much stronger instead of the reverse. The character of separation is reasonably similar in λ 4128.49 and λ 3930.84. The intensities, however, are out of all proportion to the expectations of the series law; they are what one could expect in two parallel series. It is especially noteworthy that the distances of the components of four lines are multiples of the value ± 0.20 and the components of two lines multiples of the value ± 0.30. Hence the components of the six lines are multiples of ± 0.10.

Although such a division is striking, it may be remarked that if one chooses the multiple value small enough all lines would naturally

λ	i	$-\Delta\lambda/\lambda^2$	A	B
5510.10	2+	∓0.85 *s*	7×±0.12	
	3	∓0.48 *p*	4	
4682.50	12	1.40 *s*	7×±0.20	
	10	1.19 *p*	6	
4475.90	2	(1.44)	3×±0.50	
	3	0.52	1	
4375.11	100	1.07	5×±0.20	
	100	0.20	1	
4177.68*	100	1.00	5×±0.20	$D_r b$
	100	0.44	2	$D_r b$
4167.65	20	1.20	6×±0.20†	
	20	0.59	3	
4128.49	30	1.26	4× 0.30	$D_r w$
	30	0.29	1	$D_r w$
4106.60	50	....		b_o
	30	0.40		
3982.75	60	1.17	11× 0.105	D_r†
	60	0.53	5	
3930.84	50	1.21	4× 0.30	
	6–4	0.34	1	
3833.10	30	1.34	2× 0.67	
	25	0.70	1	
3552.87	..	....		r_o
	50	0.895		
3448.98	6	1.42	3× 0.50*	
	8	0.55	1	
3200.44	20	1.53	4× 0.37	
	20	0.69	2	

* The width of the *s*-components suggests two or more components.

† When the *p*- and *s*-components of this strong line are brought into juxtaposition under the microscope, the components are clearly not related in the 1-to-2 ratio. The 12-to-5 ratio times *a*/11 (see *in/ra*) seems more probable, but the 11-to-5 ratio here given agrees better with both the old and the new readings.

fall under the multiple proportions within the limits of error. Allowing an error of only 0.05 and all lines are at once multiples of 0.1. The same may be said of the before-mentioned multiple value 0.065, and no importance, within the limits of the present reading, can be attached to such small factors. The value 0.065, or more accurately 0.06, appeared as a difference of two components, which difference was actually present when one directly compared the two plates, and the striking feature was that all components of this line were multiples of this difference. So that although errors of larger magnitude may arise, the difference is still significant of the fact that the components of lines may stand in the very simple relation of multiples of small separations. In the remaining quadruplets there can be no question of the presence of multiples of 0.20 and 0.30. There are no duplicates of the series character present.

The following 74 lines are triplets. The intensities of the undisturbed *p*-components are not given. The ratio of the intensity of the *s*- to the *p*-components is usually 1 to 2, though probably in many cases the ratio is nearer 2 to 5.

λ	*i*	$-\Delta\lambda/\lambda^2$	B	λ	*i*	$-\Delta\lambda/\lambda^2$	B
5663.1	12	∓1.10		3967.74	6	∓1.12	
30.3	2	0.74		44.90	7	1.34	n. i.
5582.1	4	0.97		06.57	5	1.48	
27.8	4–6	1.11		3878.80	15	2.34	n. i.*
5497.6	6	1.65		42.00	5	1.22	n. i.
66.7	8	1.03		3788.88	50	1.02	D_1w
03.0	6	0.79		82.50	15	1.38	
5205.9	10	1.18		76.73	15	1.49	
00.6	6	0.74		74.51	100	1.15	D_1w
5087.6	10	1.34		10.41	60	1.25	
4956.7	2+	0.48		3696.90	4	0.85	D
4900.3	20	1.10		68.67	6	1.38	
4883.9	20	1.24		64.76	30	1.74	D_1w
4855.1	15	0.92		45.67	8	1.30	n. i.
4840.1	3	1.50		35.60	5	1.16	D_1
4675.01	20	1.20		3633.28	50	1.02	
43.88	25	1.02		21.12	15	1.14	
4527.98	6	1.32		14.81	1+	(1.24)	
27.43	8	1.37		11.19	60	1.30	
06.12	15	0.92		02.12	40	0.62	
4465.50	35	1.06		00.90	75	1.48	
46.85	3	1.42		3593.11	8	0.91	
43.83	1+	....		87.86	5	1.12	
22.80	25	0.54		85.90	3		r_0
4348.91	8	1.27		49.21	50	1.67	
30.85	2	0.84		31.85	5	1.21	
09.81	50	1.33		3496.25	12	0.62	
4302.45	8	1.13		68.05	3	0.62	
4251.39	6	1.09		3372.93	6	1.25	
11.85	10	1.21		62.20	10	1.28	
04.84	20	1.61		28.11	30	1.08	
4174.27	30	1.25		20.10	1+	(1.26)	D
43.01	30	0.91	D_1w	3242.49	30	1.33	D
25.10	20	1.35		16.87	15	1.12	D_0
02.60	50	1.23		03.51	12	0.53	
4077.54	50	1.21		3173.40	5	1.23	
47.81	20	0.86		30.20	3–2	1.25	
40.00	15	1.57	D_2				

* *Y* λ 3878.47 is not present unless it should be this line, which is scarcely credible. λ 3878.80 is certainly in satisfactory agreement with the iron line λ 3878.78. But much stronger iron lines come out as impurities on the plates with much smaller intensities. The separation is unlike any other line of the triplet class in yttrium. The separation of *Fe* λ 3878.78 is unknown to the author but should the separation of the *Fe* line prove to be some other magnitude, then the present line might safely be regarded as an yttrium line, i. e., the magnetic separation may be used to determine the substance of doubtful lines. See also remarks upon *Ba* λ 6548.3, λ 6495.3, and λ 6484.7 (Table Ba_4).

Every line in the triplet class is some small multiple of the simple

values given with the lines having several components. Many of the lines, however, could safely be different multiples of more than one of these values. It is therefore of no significance so to classify the lines; e. g., a great many triplets have values approximately 1.25. If we assume 0.05 as a possible error, then any value between 1.20 and 1.30 must be considered. We then may have within these limits multiples of the intervals 0.18, 0.20, 0.30, 0.43, and 0.63. Further, if multiple relations hold and one attempts to find series in the triplet class, one is confronted by the fact that triplets of a certain magnitude may belong to quite different groups. As per above illustration, five triplets of separation 1.25 could belong to as many different groups. When we consider further the small differences in the triplets here noted, it is seen that types exist whose difference in separation is so small that a very small error in observation would place a line in a wrong type. These two considerations indicate that, if present in triplets, series can be found only with great labor; whereas in other types of separation they are, by Preston's law, at once apparent, if present at all.

VI. ZIRCONIUM

The following two lines have eleven components each:

λ 3573.30			λ 3272.39		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
5.....	−2.24 *s*	6×0.37	5.....	−2.26 *s*	6×0.37
3.....	−1.50 *s*	4	2.....	−1.54 *s*	4
3.....	−1.11 *p*	3	3.....	−1.11 *p*	3
1.....	−0.74 *s*	2	1.....	..... *s*	2
6.....	−0.34 *p*	1	5.....	−0.37 *p*	1
1.....	..... *s*	0	1.....	..... *s*	0
6.....	+0.34 *p*		5.....	+0.37 *p*	
1.....	..... *s*		1.....	+.... *s*	
3.....	+1.03 *p*		3.....	+1.14 *p*	
3.....	+1.50 *s*		2.....	+1.50 *s*	
?.....	+.... *s*	b_o	5.....	+2.26 *s*	

These two lines are certainly duplicates. The *s*-components are even multiples of 0.37 and the *p*-components are odd multiples of the same value. A common difference of 0.74 occurs six times in each of these lines.

The following two lines have nine components each:

λ 3780.78			λ 3921.99		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
6.....	−2.17 *s*	5×0.43	4.....	−2.14 *s*	5×0.43
2.....	−1.69 *s*	4	1.....	.....	
2.....	−0.86 *p*	2	2.....	−0.92 *p*	2
3.....	−0.42 *p*	1	3.....	−0.44 *p*	1
3.....	0.00 *p*	0	3.....	0.00 *p*	0
3.....	+0.48 *p*		2.....	+0.46 *p*	
1+.....	+0.90 *p*		1+.....	+0.91 *p*	
2.....	+1.69 *s*		1.....	.....	
6.....	+2.17 *s*		4.....	+2.14 *s*	

These lines are duplicates and the separations are multiples of the value 0.43.

The following six lines have eight components each:

λ 4440.80			λ 4268.22		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
2.....	−2.14 *s*		10.....	−2.16 *s*	4×0.54
4.....	−1.57 *s*		8.....	−1.09 *p*	2
2.....	−1.04 *s*		6.....	−1.07 *s*	
15.....	−0.89 *p*		3 *s*	0.00	
15.....	+0.89 *p*	9×0.10	12 *p*		
2.....	+0.98 *s*	10	8.....	1.07 *p*	
4.....	+1.57 *s*	16	6.....	1.12 *s*	
2.....	+2.18 *s*	22	10.....	2.16 *s*	

λ 4214.05			λ 4027.4		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
6.....	−1.76 *s*	3×0.60	2.....	−1.94 *s*	7×0.27
6.....	−1.21 *p*	2	3.....	−1.36 *s*	5
2.....	−1.17 *s*	2	8.....	−1.09 *p*	4
10 *p*	0.00		2.....	−0.75 *s*	3
1 *s*			2.....	+0.87 *s*	
6.....	+1.07 *p*	0	8.....	+1.09 *p*	
2.....	+1.13 *s*		3.....	+1.37 *s*	
6.....	+1.75 *s*		2.....	+1.94 *s*	

λ 3764.6			λ 3459.1		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
2.....	1.82 *s*	7×0.27	3.....	−2.20 *s*	22×0.10
3.....	1.35 *s*	5	4.....	−1.51 *s*	15
8.....	1.08 *p*	4	8.....	−1.17 *p*	12
2.....	0.86 *s*	3	2.....	−0.73 *s*	7
1+.....	0.86 *s*		3.....	+0.68 *s*	7
8.....	1.08 *p*		8.....	+1.17 *p*	12
3.....	1.35 *s*		4.....	+1.54 *s*	15
1+.....	1.89 *s*		1+.....	+2.28 *s*	23

λ 4027.4 and λ 3764.6 are probably duplicates.

The following seven lines have seven components each:

λ 4457.71			λ 4258.31		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
2.....	−2.31 *s*		4.....	−1.53 *s*	6×0.26
10.....	−1.46 *s*		6.....	−1.37 *p*	5 (?)
10.....	−1.33 *p*		2.....	−(0.82) *p*	3
2.....	0.00 *p**		10.....	0.00	0
10.....	+1.46 *s*		2.....	+(0.82) *p*	8×0.10
10.....	+1.50 *p*		6.....	+1.37 *p*	14
2.....	+2.31 *s*		4.....	+1.48 *s*	15

λ 4171.65 †			λ 4093.32		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
8.....	−1.48 *s*	6×0.25	1+.....	−1.77 *s*	6×0.305(?)
8.....	−1.26 *p*	5	2.....	−0.90 *p*	3
6.....	−0.26 *s*	1	2.....	−0.67 *s*	2?
6.....	0.00 *p*	0 (?)	3.....	0.00 *p*	0
6.....	+0.26 *s*		3.....	+0.66 *s*	7×0.10
4.....	+1.24 *p*		2.....	+0.93 *p*	9
3.....	+1.50 *s*		1+.....	+1.78 *s*	18
2.....	+(3.02) *s*	12 (?)(*a*)			

λ 4068.9			λ 4055.2		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
2.....	−1.55 *s*		2.....	−1.11 *s*	2×0.53
2.....	−1.16 *p*		6.....	−0.56 *p*	1
2.....	−0.49 *s*		8.....	−0.53 *s*	1
6.....	0.00 *p*‡		8.....	0.00 *p*	0
2.....	+0.49 *s*		4.....	+0.49 *p*	
2.....	+0.83 *p*		8.....	+0.53 *s*	
2.....	+1.55 *s*		2.....	+1.11 *s*	

λ 3368.01		
i	Δλ/λ²	A
1.....	−1.71 *s*	4×0.43
8.....	−1.25 *p*	3
2.....	−0.88 *s*	2
3.....	0.00 *p*	0
2.....	+0.88 *s*	
8.....	+1.26 *p*	
1+.....	+1.68 *s*	

* The weak middle *p*-component is unsymmetrical.

† The line is unsymmetrical in intensity and has a possible extra component (*a*) upon the violet side This line may be also a foreign line as it does not appear upon the plates with weaker fields.

‡ The outer weak pair of *p*-components is not symmetrical.

The following sixteen lines have six components each:

λ 4590.81			λ 4438.23		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
2.....	−1.74 *s*	3×0.55	2.....	−1.57 *s*	3×0.52
6.....	−1.11 *p*	2	6.....	−1.07 *p*	2
2.....	−0.55 *s*	1	2.....	−0.57 *s*	1
2.....	+0.55 *s*		2.....	+0.55 *s*	6?×0.10
5.....	+1.11 *p*		6.....	+1.07 *p*	11
2.....	+1.67 *s*		2.....	+1.60 *s*	16

λ 4431.70			λ 4403.67		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
6.....	−2.73 *s*	5×0.55	5.....	−2.11 *s*	8×0.26
6.....	−1.67 *s*	3	15.....	−0.76 *p*	3
12.....	−1.12 *p*	2	12.....	−0.48 *s*	2
12.....	+1.12 *p*		12.....	+0.48 *s*	
6.....	+1.67 *s*		15.....	+0.76 *p*	
6.....	+2.74 *s*		5.....	+2.11 *s*	

λ 4110.29			λ 4040.49		
i	Δλ/λ²	A	*i*	Δλ/λ²	A
6.....	−1.54 *s*	4×0.39	2.....	−2.08 *s*	8×0.26
8.....	−1.17 *p*	3	10.....	−0.77 *p*	3
1+.....	−0.77 *s*	2	8.....	−0.51 *s*	2
1+.....	+0.77 *s*		8.....	+0.51 *s*	
8.....	+1.17 *p*		10.....	+0.77 *p*	
6.....	+1.54 *p*		2.....	+2.12 *s*	

λ 3554.31		
i	Δλ/λ²	A
2.....	−2.67 *s*	6?×0.43
6.....	−1.72 *s*	4
10.....	−0.42 *p*	1
10.....	+0.42 *p*	4×10
6.....	+1.72 *s*	17
2.....	+2.67 *s*	27

λ 3507.80		
i	Δλ/λ²	A
6.....	− 2.78 *s*	?
1+.....	−(1.05) *s*	
5.....	− 0.90 *p*	
5.....	+ 0.90 *p*	
1+.....	+(1.08) *s*	
6.....	+ 2.75 *s*	

λ 3498.00		
i	Δλ/λ²	A
8.....	−2.51 *s*	5×0.50
2.....	−1.48 *s*	3
12.....	−0.44 *p*	1?
12.....	+0.44 *p*	
2.....	+1.48 *s*	
8.....	+2.45 *s*	

λ 3483.70		
i	Δλ/λ²	A
4.....	−1.82 *s*	5×0.36
16.....	−1.08 *s*	3
20.....	−0.38 *p*	1
20.....	+0.38 *p*	
16.....	+1.08 *s*	
4.....	+1.80 *p*	

λ 3482.96		
i	Δλ/λ²	A
4.....	−1.10 *s*	3×0.36
4.....	−0.72 *p*	2
4.....	−0.70 *s*	2
4.....	+0.70 *s*	
6.....	+0.72 *p*	
4.....	+1.10 *s*	

λ 3396.51		
i	Δλ/λ²	A
2.....	−1.06 *p*	3×0.34
6.....	−0.67 *s*	2
6.....	−0.33 *p*	1
6.....	+0.33 *p*	
6.....	+0.67 *s*	
2.....	+0.95 *p*	

λ 3323.21		
i	Δλ/λ²	A
8.....	− 1.91 *s*	5×0.38
2.....	−(1.15) *s*	3
12.....	− 0.41 *p*	1
12.....	+ 0.41 *p*	
2.....	+(1.15) *s*	
8.....	+ 1.91 *s*	

λ 3318.70		
i	Δλ/λ²	A
.....	−(1.53) *s*	
1+.....	−(1.72) *s*	
5.....	− 0.69 *p*	
5.....	+ 0.69 *p*	
1+.....	+(0.74) *s*	
5.....	+ 1.45 *s*	

λ 3313.89		
i	Δλ/λ²	A
1+.....	−(2.39) *s*	6×0.40
8.....	− 1.69 *s*	4
6.....	− 0.40 *p*	1
6.....	+ 0.40 *p*	4×0.10
8.....	+ 1.68 *s*	17
1+.....	+(2.39) *s*	24

λ 3155.90		
i	Δλ/λ²	A
2.....	−2.10 *s*	8×0.26
6.....	−0.77 *p*	3
8.....	−0.51 *s*	2
8.....	+0.51 *s*	
6.....	+0.77 *p*	
2.....	+2.10 *s*	

The following eleven lines have five components each:

λ 5350.5		
i	Δλ/λ²	A
8.....	−1.42 *s*	3×0.48
4.....	−0.49 *p*	1
2.....	0.00 *s*	0
3.....	+0.49 *p*	
4.....	+1.44 *s*	

λ 4236.23		
i	Δλ/λ²	A
8.....	−1.47 *s*	
2.....	−0.66 *p*	
4.....	0.00 *p*	
2.....	+0.66 *p*	
8.....	+1.47 *s*	
2.....	(2.20) ? *s*	

λ 4187.30		
i	Δλ/λ²	A
5.....	−2.92 *s*	9×0.32
4.....	−1.26 *p*	4
8.....	0.00 *p*	0
4.....	+1.24 *p*	
5.....	+2.92 *s*	

λ 4061.70		
i	Δλ/λ²	A
10.....	−1.79 *s*	7×0.26
4.....	−0.52 *p*	2
6.....	0.0 *p*	0
3.....	+0.51 *p*	
10.....	+1.79 *p*	

λ 4046.30		
i	Δλ/λ²	A
2.....	−1.65 *s*	2×0.83
4.....	−0.84 *p*	1
8.....	0.00 *s*	0
4.....	+.... *p*	
2.....	+1.65 *s*	

λ 3501.50		
i	Δλ/λ²	A
6.....	− 2.00 *s*	3×0.67
4.....	−(0.70)	1
2.....	0.00 *s*	0
2.....	+(0.70) *p*	7×0.10
4.....	+ 2.00 *s*	20

λ 3471.31		
i	Δλ/λ²	A
6.....	−0.87 *s*	9×0.10
12.....	−0.30 *p*	3
6.....	+0.30 *p*	3
4.....	+0.49 *s*	5
2.....	+1.20 *s*	12

λ 3432.59		
i	Δλ/λ²	A
2.....	−1.71 *s*	
8.....	−0.94 *p*	
15.....	0.0 *s*	
8.....	+0.94 *p*	
2.....	+1.71 *s*	

λ 3376.42		
i	Δλ/λ²	A
2.....	−1.10 *s*	3×0.37
2.....	−0.38 *p*	1
10.....	0.00 *s*	0
2.....	+0.38 *p*	
1+.....	+1.17 *s*	

λ 3271.30		
i	Δλ/λ²	A
2.....	−(1.38) *s*	
8.....	− 0.63 *p*	
12.....	0.00 *s*	
8.....	+ 0.63 *p*	
2.....	+(1.38) *s*	

λ 3099.42		
i	$\Delta\lambda/\lambda^2$	A
1+.....	.....	
5.....	−1.31	
3.....	0.0	
5.....	+1.31	
1+.....	.....	

The line λ 5350.5 is unsymmetrical in intensity; λ 3471.31 is unsymmetrical in intensity as well as in separation. Duplicates are not present.

The following eighty-nine lines have four components each:

λ	i	$\Delta\lambda/\lambda^2$	A	λ	i	$\Delta\lambda/\lambda^2$	A
4582.50	3	∓1.02s	2×0.51	4036.10	20	∓1.30	4×0.33
	2	0.52p	1		20	0.67	2
4456.50	30	0.83	3×0.28	4034.30	6	1.33	4×0.33
	30	0.56	2		4	0.32	1
4455.64	2	1.20	3×0.42	4031.57	2	1.66	4×0.42
	2	0.84	2		3	0.41	1
4455.08	12	1.21	3×0.42	4025.16	25	(1.39)	
	15	0.46	1		25	0.73	
4429.28	3	1.58	3×0.51	4024.20	25	1.54	3×0.51
	5, 3	0.49	1		20	0.55	1
4420.70	15	1.82		4017.16	6	1.13	3×0.42
	15	0.71			8	0.43	1
4414.80	20	1.58	5×0.32	4004.51	2	1.00	5×0.20
	20	0.63	2		5	0.79	4
4413.28	12	1.76		4003.28	8, 10	2.05	7×0.29
	15	0.53			6, 4	0.29	1
4394.73	....	....		3999.18	100	1.17	3×0.42
	7, 5	0.60			100	0.85	2
4349.10	2	(1.23)	3×0.40	3973.68	20	1.14	2×0.57
	2	0.77	2		15	0.57	1
4312.47	4	1.27	3×0.42	3934.99	20	1.14	2×0.57
	4	0.41	1		15	0.57	1
4309.20	8	1.25	3×0.42	3916.16	25	0.85	4×0.22
	8	0.85	2		20	0.24	1
4256.66	6	1.50	6×0.25	3894.00	5, 3	(0.89)	4×0.22
	6, 4	0.27	1		2, 4	(0.67)	3
4224.42	....	....		3891.61	25	1.28	13×0.10
	5	1.08			25	0.70	7
4199.30	15	1.47	3×0.48	3890.58	30	1.29	4×0.30
	12	0.46	1		30	0.29	1
4077.27	....	....		3817.80	30, 20	0.81	
	5	0.38			20	0.35	
4071.30	8	1.68		3782.45	3, 5	(0.72)	
	10	0.58			7	0.73	
4043.77	15	1.48	3×0.50	3674.98	50	0.63	3×0.21
	15	0.54	1		50	0.42	2

λ	i	Δλ/λ°	A	λ	i	Δλ/λ°	A
3663.81	20	∓1.27	3×0.42	3394.96	4	∓1.76	
	15, 12	0.42	1		4	0.94	
3650.90	6	1.49	2×0.75	3378.47	4	....	
	5	0.76	1		4	1.43	
3634.33	10	1.36	4×0.34	3377.61	8	1.45	
	10, 6	0.35	1		6, 4	0.61	
3629.29	2	1.09		3369.42	4	1.64	4×0.42
	2	0.71			4	0.44	1
3624.10	25	1.16		3364.00	8	1.33	3×0.42
	25, 20	0.33			8	0.84	2
3613.30	40	(1.03)		3357.42	25, 20	0.59	3×0.20
	30	0.95			25, 20	0.40	2
3612.61	3	0.59		3338.07	4	1.98	
	3	0.41			2	1.17	
3588.15	20	0.58	2×0.29	3310.10	4	....	
	20	0.29	1		4	1.45	
3578.40	20	2.01	7×0.29	3296.59	6	1.49	3×0.50
	20, 15	0.28	1		4	(0.47)	1
3569.03	2	....		3287.46	2	....	
	2	0.47			2	0.54	
3568.32	6	1.17	4×0.30	3284.89	20	0.65	2×0.33
	6	0.90	3		20	0.35	1
3552.20	50	1.27	3×0.42	3274.14	4	1.46	2×0.75
	50	0.77	2?		4	0.78	1
3530.17	6	1.21	3×0.42	3264.96	4	1.46*s*	3×0.50
	5, 4	0.45	1		4	(0.51)*p*	1
3514.79	4	1.23	3×0.42	3229.00	15	1.36	3×0.45
	4	0.84	2		15, 12	0.46	1
3505.67	60	1.67	4×0.42	3213.01	4	1.10	2×0.53?
	60	0.41	1		4	0.50	1
3480.59	15	1.57	3×0.51?	3182.15	....	....	
	15	0.98	2		5	0.67	
3478.98	2	(0.87)		3181.79	8	1.56	
	6	0.50			8	1.45	
3470.10	2	(1.59)	6×0.27	3178.30	8	1.65	4×0.42
	4	1.33	5		8	0.87	2
3460.10	2, 3	(1.22)		3166.48	....	....	
	3	0.72	2		6	0.61	
3454.71	3	0.61	1×0.60	3165.68	4	1.60	
	4	1.18	2		4	0.49	
3440.54	5	0. +*s*	*p*>*s*	3164.54	12	1.09	11×0.10
	6	1.11*p*			6	0.40	4
3437.30	25	1.42	2×0.71	3157.19	6	1.16	3×0.42?
	25	0.72	1		3	0.81	2
3434.08	5	1.58	4×0.39	3111.09	4	1.46	
	10	1.19	3		6	0.55	
3424.97	4	0.93	2×0.42?	3095.29	8	1.25	5×0.25
	10, 8	0.41	1		8	0.76	3
3413.55	2	(1.55)	13×0.12	3031.04	3	....	
	4	1.43	12		2	0.66	

A simple relationship between the components of a line appears for a great majority of these quadruplets. The interval 0.42 repeats itself very often in many lines, but the factors by which this interval must

be multiplied in order to obtain the separation of the lines are different, so that few duplicates occur. Some of the lines are evidently pairs. A well-defined line, λ 4455.08, the distance of whose components are three and one times the value 0.42, is accompanied on the red side by a weak line whose separation is three and one times the same value 0.42. The difference in vibration-frequency of these two lines is 2.62. λ 3663.81 is a duplicate of λ 4455.08, but is not accompanied by a weak line. There are two pairs of lines whose separation is in the ratio of three to one for the pair of greater wave-length, and in the ratio of three to two for the pair of shorter wave-length. This first pair is λ 4312.47 and λ 4309.20 with a vibration difference of 12.21. The second pair is λ 3530.17 and λ 3514 with a vibration difference of 123.95. One can associate with the last pair the very strong line λ 3507.67, whose components have the separation of four and one times the value 0.42. There appears also another pair whose components stand in the ratios of three to one and four to one times the value 0.42. These lines are λ 3364 and λ 3369.42, which gives a vibration difference 47.82. In the lines λ 3164.54 and λ 3157.19 there exist possibly the ratios of three to one and three to two times the value 0.42 respectively. The vibration difference is 73.46. These differences in vibration have no uniformity, such as one expects in corresponding terms of similar series. It is possible that λ 3999.18, the strongest line of the spectrum, and λ 3552.2 belong to the three to two multiples of 0.42, but this value does not repeat itself in other strong lines.

The zirconium triplets have not been thoroughly investigated for series. Such an investigation of so many lines would require a long time. For reasons given in the discussion of yttrium triplets, and here even more pronounced, the application of Preston's law is neither immediate nor direct, and the necessary work would be enormous. However, I have investigated the separations 0.59 ± 0.07, 0.76 ± 0.07, 0.84 ± 0.08, 1.25 ± 0.07, 1.66 ± 0.07, 1.82 ± 0.09, and 2.34.

The following four hundred and ten lines are triplets:

λ	i	$\Delta\lambda/\lambda^2$	λ	i	$\Delta\lambda/\lambda^2$
5665.4	2, 4	(∓1.25)	4542.49	12, 25	∓1.59
36.0	1+, 3	(0.83)	40.19	2, 6	(1.31)
5504.7	6, 12	0.59	36.00	10, 20	0.94
02.5	6, 12	0.99	23.44	3, 6	1.35
5492.1	5, 10	0.83	07.39	8, 15	1.10
69.8	8, 16	0.56	4497.27	30, 60	0.94
65.8	1+, 3	(1.01)	94.78	15, 30	1.20
53.8	6, 12	0.66	85.71	2, 4	(2.35)
46.0	6, 10	0.76	82.72	4, 8	1.24
00.7	8, 15	0.68	81.00	5, 10	1.28
5385.6	8, 15	1.24	70.80	10, 20	1.08
57.5	8, 15	0.66	68.98	3, 8	1.29
5191.7	10, 20	1.30	67.12	6, 12	1.53
43.5	6, 12, 8	0.62	61.50	8, 15	1.18
38.4	10, 20	0.62	60.57	2, 4	1.27
14.2	2, 4	(0.90)	50.71	5, 10	2.73
5079.6	1+, 3	(0.62)	43.41	30, 60	1.07
66.9	2, 5	0.95	29.55	1+, 3	(1.61)
4839.3	2, 5, 4	0.75	27.44	8, 15	1.09
28.5	4, 6, 3	0.70	04.98	6, 12	1.44
24.8	4, 8	1.27	4383.90	6, 12	1.31
16.1	12, 24	0.78	80.12	50, 100	1.15
10.0	4, 8	1.19	73.28	1+, 3	(2.32)
06.5	4, 8	1.27	71.27	20, 40	1.18
4789.3	3, 6	0.95	66.69	15, 30	1.22
85.6	6, 12	0.99	61.01	6, 12	1.62
72.1	15, 30	0.90	60.05	50, 100	1.26
62.8	2, 4	1.13	58.95	5, 10	1.32
39.6	20, 4	1.04	48.15	50, 100	1.12
19.3	8, 16	1.17	46.70	5, 10	0.84
12.2	3, 6	1.31	43.59	1+, 3	(1.23)
10.3	25, 50	1.18	43.23	2, 4	1.06
03.3	2, 4	(1.41)	41.40	5, 10	1.36
4688.7	5, 8	1.14	39.80	3, 6	1.86
88.0	30, 60	1.32	37.90	8, 15	1.34
85.5	3, 8	1.11	33.59	15, 30	1.24
83.6	8, 16	1.19	24.24	8, 15	1.06
67.4	1+, 3	(1.24)	19.24	4, 8	1.24
62.0	3, 8	1.05	17.57	12, 25	1.26
57.9	4, 8	1.18	09.99	4, 8	1.68
45.01	6, 12	0.76	04.92	8, 15	1.45
34.20	15, 30	1.09	03.12	20, 40	1.67
29.33	6, 12	1.20	02.80	2, 4	1.67
26.62	8, 15	1.21	02.10	8, 16	0.88
14.20	6, 12	1.03	4297.00	12, 25	1.50
04.59	3, 6	2.34	95.08	25, 50	1.69
02.80	10, 20	1.27	93.41	15, 30	0.75
4584.44	1+, 3	(1.02)	91.54	5, 10	1.63
76.37	1+, 3	0.71	91.38	4, 8	1.62
75.78	15, 30	0.91	86.78	6, 12	0.76
74.78	6, 12	0.94	82.53	8, 15	1.82
65.68	3, 6	0.95	77.60	6, 12	1.42
54.29	8, 16	1.10	76.91	6, 12	1.67
53.25	3, 6	0.54	74.95	6, 12	1.20

λ	i	Δλ/λ²	λ	i	Δλ/λ²
4265.17	4, 8	∓1.52	4078.49	6, 12, 8	∓1.66
61.65	6, 12	1.11	76.70	8, 15	1.26
61.42	2, 5	(1.90)	75.09	12, 20	1.67
53.76	8, 15	2.14	72.90	40, 75	1.27
43.74	2, 4	(1.44)	64.38	25, 50	1.05
41.98	20, 40	1.27	60.78	6, 10	1.03
41.50	15, 30	1.11	58.78	4, 8	0.88
39.58	30, 20	1.49	55.90	15, 25	1.32
37.57	4, 8	2.18	54.60	2, 4	0.56
36.81	6, 12	(0.85)	50.52	30, 50	1.37
34.89	8, 16	1.25	48.90	30, 50	1.34
31.88	10, 20	1.34	45.90	25, 40	0.61
27.98	40, 60	1.51	42.49	8, 15	(1.38)
22.67	4, 8	0.70	41.90	10, 20	(1.64)
18.60	4, 8	1.86	30.87	2, 4	0.96
15.95	4, 8	0.84	29.88	30, 50	1.77
15.50	6, 12	1.42	29.17	6, 12	1.74
12.17	25, 50	0.62	24.70	20, 40	(1.39)
11.50	4, 8	1.57	18.60	15, 30	1.02
10.87	10, 20	1.57	12.48	8, 15	0.94
09.21	50, 100	0.97	07.80	10, 20	1.08
01.69	20, 50	1.69	05.02	6, 12	(1.57)
4196.32	8, 15	1.35	3991.31	100, 150	1.08
95.00	10, 20	1.84	89.65	10, 15	1.33
94.66	2, 4	1.20	84.90	10, 20	1.57
92.03	4, 8	(1.14)	81.79	20, 40	1.35
91.75	3, 5	0.77	78.86	6, 12	1.47
87.80	20, 30	1.60	78.35	2, 4	(1.04)
86.89	20, 30	1.63	77.60	10, 20	1.06
83.51	10, 20	1.77	75.47	12, 30	1.22
80.08	25, 40	1.40	68.39	10, 20	1.16
68.90	6, 10	1.28	66.80	10, 20	1.69
66.60	15, 30	1.50	61.71	12, 25	1.29
61.48	30, 50	0.71	58.39	75, 125	0.98
53.96	8, 15	2.38	56.90	3, 6	0.62
52.87	15, 30	1.59	41.75	10, 15, 8	1.01
51.23	20, 50	1.39	36.28	12, 25	1.88
49.43	150, 300	1.27	31.55	2, 4	+1.66
47.53	6, 10	1.20	29.71	30, 50	1.14
40.70	5, 10	1.86	26.96	3, 6	1.19
38.02	6, 10	0.33	20.35	2, 4	(1.67)
35.85	10, 20	1.50	18.25	1+, 3	(0.50)
34.46	4, 8	(1.66)	16.80	6, 12	1.42
21.68	12, 20	1.70	14.59	10, 20	0.94
08.60	10, 20	1.67	00.08	2, 4	(1.65)
07.75	6, 10	0.99	3897.82	5, 10	1.43
4099.50	4, 6	(1.89)	96.73	10, 20	1.18
96.80	15, 30	0.90	92.19	6, 12	1.21
94.42	6, 10	1.46	85.61	12, 25	1.11
91.00	6, 10	0.66	79.21	10, 20	1.35
90.70	30, 50	0.91	77.78	12, 25	1.10
89.98	8, 15	1.00	64.57	25, 50	1.32
87.88	5, 10	1.74	64.12	30, 50	1.20
84.50	8, 15	1.18	49.48	15, 25	1.35
83.29	6, 12	1.58	47.22	12, 20	1.28
81.48	30, 50	1.33	43.30	25, 50	1.05

λ	i	Δλ/λ²	λ	i	Δλ/λ²
3836.98	75, 150	∓1.24	3566.30	15, 25	∓1.23
36.18	25, 50	0.76	65.51	10, 20	0.93
22.60	15, 30	0.85	59.23	6, 10	0.80
00.91	5, 10	1.44	56.89	75, 125	0.94
3796.71	30, 50	1.80	50.67	8, 20	1.40
92.55	10, 20	1.38	49.73	20, 30	1.60
91.60	15, 25	1.52	47.90	20, 30	1.39
86.80	4, 8	1.34	42.87	40, 60	1.23
82.99	3, 6	(0.92)	39.17	5, 8	1.77
82.45	3, 6	(0.72)	37.11	10, 15	1.24
72.29	10, 20	1.55	35.30	6, 10	1.28
66.99	50, 100	1.15	33.35	12, 20	1.83
59.30	3, 6	1.27	31.00	10, 20	1.17
57.99	12, 25	1.31	27.58	15, 25	1.19
51.85	75, 150	1.02	26.00	25, 40	1.70
50.84	10, 20	1.30	21.01	12, 20	1.93
46.18	50, 100	1.19	19.72	25, 40	1.19
38.32	6, 10	1.47	10.61	8, 12	1.72
37.54	4, 8	1.03	09.48	20, 30	1.23
35.15	12, 20	1.52	06.23	10, 15	1.89
31.50	30, 50	0.97	05.88	75, 125	(1.44)
29.98	8, 15	1.87	00.33	5, 10	1.04
27.90	15, 20	1.60	3499.78	20, 30	1.64
19.02	8, 12	1.59	96.40	60, 100	1.10
14.99	30, 50	1.46	83.17	3, 5	(1.38)
14.30	6, 10	2.05	81.36	50, 100	1.19
09.51	40, 75	1.20	79.58	10, 15	(1.07)
3698.41	75, 125	1.26	78.68	8, 12	1.63
97.70	20, 40	1.28	78.45	6, 10	1.74
79.80	1+, 3	(1.37)	63.23	30, 50	1.05
79.10	15, 25	1.24	61.22	6, 10	1.38
72.81	3, 5	2.85	57.75	25, 30	1.33
71.49	25, 40	0.99	57.30	2, 3	(1.98)
68.69	15, 25	1.73	56.02	3, 5	0.59
67.28	6, 12	1.32	47.50	10, 15	0.66
62.32	10, 20	0.95	46.71	5, 8	0.88
61.10	3, 5	0.57	43.69	10, 15	0.71
55.72	8, 15	1.74	40.70	2, 3	(1.35)
53.61	2, 4	1.17	38.39	100, 150	1.25
51.65	2, 4	(1.44)	30.73	40, 40	1.32
36.69	15, 25	1.69	27.23	1+, 3	(1.76)
33.70	12, 20	1.29	24.00	2, 4	1.49
30.30	20, 40	1.89	19.76	3, 6	0.81
19.22	6, 12	0.83	19.22	6, 6	2.02
12.13	30, 50	1.44	14.87	15, 15	0.86
07.60	15, 30	1.48	10.44	30, 25	1.24
01.40	40, 75	1.24	08.23	12, 10	0.52
00.11	10, 15	1.11	05.04	25, 20	0.98
3588.96	3, 6	1.71	03.89	12, 10	0.60
88.51	12, 20	1.66	03.10	10, 8	1.69
86.42	15, 20	0.75	3399.95	1+, 3	(1.61)
77.74	5, 8	1.16	99.51	10, 15	0.63
77.10	50, 75	1.39	96.81	2, 3	1.06
75.89	15, 25	1.35	94.96	3, 5	1.76
72.70	75, 125	1.04	93.36	15, 12	1.62
70.25	6, 12	1.11	92.20	75, 75	1.26

λ	i	Δλ/λ²	λ	i	Δλ/λ²
3388.49	40, 40	∓1.63	3234.24	10, 12	∓1.19
88.07	40, 40	0.75	31.89	40, 50	1.71
83.90	2, 4	0.89	29.00	15, 20	1.37
74.84	30, 15	1.50	22.61	8, 10	1.28
73.61	15, 8	1.04	14.35	40, 50	1.70
73.05	4, 6	1.05	12.17	8, 12	1.12
70.73	4, 6	1.53	3192.11	8, 12	1.27
61.35	4, 6	1.15	91.31	4, 6	0.93
60.61	4, 6	1.50	83.08	30, 40	1.14
60.18	12, 10	1.03	61.12	2, 4	0.94
56.28	25, 20	1.73	57.94	4, 8	0.96
54.59	12, 10	1.48	38.88	20, 30	1.14
49.59	4, 4	1.12	37.08	2, 4	(1.43)
49.23	2, 2	1.02	33.70	15, 20	1.17
45.00	15, 15	1.14	32.22	2, 4	(1.09)
44.00	1+, 3	1.18	29.96	20, 30	1.01
42.10	1+, 3	1.09	29.38	20, 30	0.95
27.05	15, 12	1.26	26.10	15, 20	0.55
19.19	8, 6	1.63	25.33	1+, 3	(1.03)
11.53	3, 3	1.73	20.90	4, 8	1.32
06.48	30, 20	1.11	11.09	6, 10	1.46
05.33	25, 25	1.39	06.79	25, 40	1.32
02.89	8, 6	1.43	3055.00	15, 25	1.20
3288.99	12, 10	1.92	36.57	8, 12	1.55
86.01	8, 8	1.79	29.63	6, 10	1.23
85.89	2, 2	1.78	28.18	10, 15	1.00
83.09	10, 8	1.32	20.53	5, 8	1.29
80.92	2, 2	0.69	19.96	1+, 3	1.19
75.28	2, 2	1.24	11.88	4, 6	1.11
74.14	4, 3	1.46	03.88	6, 10	1.37
73.22	40, 50	1.45	2985.53	4, 6	0.75
69.81	4, 4	1.38	81.18	3, 5	(1.60)
60.24	4, 4	1.42	79.35	2, 4	1.29
50.62	10, 4	1.98	78.21	4, 6	1.55
47.72	6, 6	1.14	69.77	6, 10	0.56
42.32	3, 3	1.38	69.10	6, 10	1.58
41.26	20, 20	1.14	62.81	5, 10	1.05
36.75	3, 4	1.68	55.92	8, 12	1.11

The following 29 lines are apparently not separated. Most of them are, as the footnotes to the table indicate, probably of some other types, whose components have too small a separation and are too diffuse to permit of an analysis. The lines designated A are certainly not separated and those undesignated in column B are probably not separated. The lines designated (†) in remarks are very curious and probably identical. λ 5736.0, λ 4240.39, λ 3900.71 would form a series, but the next term about λ 3750 and the following terms are not present.

λ	i	B	λ	i	B
5508.5	8	D	4030.26	8	‡
5485.4	8		3989.27	2	n. i.
5136.0	10		00.71	15	¶
4851.8	6	*b* D	3781.80	8	‖ D
15.4	4	D	24.94	5	
4400.58	6	D*	06.79	5	D*w*
4273.80	12	†	3657.01	2	§
66.96	4		3549.90	5	
50.89	1+	D*w*	3431.71	8	†
40.59	20	A	3362.87	8	¶
13.45	5	A	3354.08	3	n. i. **
4181.13	8		3314.70	15	†
40.18	5	D somewhat	3131.23	1+	D*w*
28.08	12	A	3013.44	1+	††
4044.80	20	A			

* Possibly there is a weak pair of external components.

† *s*-component is a strong center with a broad background of diffusion on both sides; *p*-component wide.

‡ The *p*-component is broadened.

¶ Broad line for the *s*-component, sharp and strong on the edges and weak in the center; *p*-component sharp.

‖ The real components are probably overlapped by a carbon band line.

§ Possibly separated, but too weak.

** Not identified. It can scarcely be Exner and Haschek's line 3353.80.

†† Too weak and diffuse. It is possibly a doublet, but too far in violet for analysis.

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λ	i	Δλ/λ²	λ	i	Δλ/λ²
4420.63	25	∓1.20 *s*	3882.03	7	∓1.65
	25	0.70 *p*	3794.05	4	1.29
4395.05	4	1.49	90.28	6	1.83
28.84	4	1.19	82.37	12	1.82
11.15	6	0.94	52.71	20	1.63
4294.17	8	1.18	3598.26	2+	(1.55)
		0.47	3561.04	8	1.35
61.01	20	1.95	59.96	4	1.58
12.02	12	1.72	28.76	5	1.61
4175.74	5	1.49	04.83	4	1.55
73.42	10	1.44	3402.03	3	1.50
35.95	15	1.97	3301.75	12	1.68
12.17	10	1.65	3268.09	6	1.61
4091.99	3	1.81	3262.44	4	1.37
66.90	8	1.54	3156.38	4	1.62
3977.38	6	1.54	3058.77	8	1.55
63.79	8	1.59	2909.19	10	1.40

Osmium was selected as a substance which, it was hoped, would give, with some types, repetitions throughout the spectrum, without having the confusion which arises from many lines of nearly the same

separation. In this respect the substance was a disappointment. All the lines except one weak quadruplet are triplets and the separation of these varies from 0.70 to 1.97. There are a number of pairs of similar separation, but not enough representatives for a series. The spectral lines were never strong. Therefore, a long exposure in the magnetic field was required. A characteristic of the components is their great sharpness. The unrecorded *p*-components have very uniformly double the intensity of the *s*-components.

VIII. COMPARISON OF SUBSTANCES

It is desirable to compare the substances discussed above with lines whose separations give series. The two yttrium lines, λ 4395.91 and λ 3195.80, which are accurate duplicates such as one expects in series, are like six of the nine components of mercury, λ 5461 of the second adjacent series. The quadruplet λ 4167.65 is like four components of the barium sextet λ 5854. The quadruplet λ 3982.75 is like four components of the thirteen component mercury line λ 3663.5. The remaining components in these three lines are not absent because of weakness, since these lines are not weak lines. The two eleven component zircon lines have two pairs of components similar to two pairs of components in the nine component mercury line λ 5461. They have two other pairs of components represented in the barium principal series greater wave-length λ 4934. Their one remaining pair of components is found in barium principal series smaller wave-length λ 4554. That is, the components of these two lines are represented in three series types. There are other lines, both in yttrium and in zirconium, whose components can be selected by using more than one line of barium and mercury. Such a comparison points to a difference in the character of the lines rather than to an identity. From a glance at the tables it is seen that the components of lines are multiples of intervals; further, that the lines under comparison are likewise multiples of the same intervals, but that the multiples are only partially identical when they have the same interval, and the components have the same multiple proportions. One may further add, the components should have the same relative intensity. This is the condition fulfilled in the principal and subordinate series. The quadruplets of the principal series are 4 and 2 times the interval ± 0.37 $(=\Delta\lambda/\lambda^2)$, for

field-strength 24,400, and the sextuplets 5, 3, and 1 times the the same values.

While I was engaged in making these comparisons an investigation bearing directly upon this point was published by Professor Runge.[1] I have accordingly tabulated the intervals from Professor Runge's contribution, intervals from his previous contributions, and the intervals in the present substances, all in one table which presents the matter more clearly than any verbal description. An interval multiplied by multiple "factors" (small whole numbers) constitutes a type by Preston's law. I have tried to find only representatives of Professor Runge's types, rather than all the lines and all the substances of these types. By way of explanation, the value "a" in the following table corresponds to the separation of 1.11 for present field-strength, and is the separation designated "normal triplet" by Professor Runge. This triplet gave him the value of 1.75×10^7 for e/m (charge/mass) in the equation, $a = \Delta\lambda/\lambda^2 = (e/m)\ (H/4\pi c)$, where c is the velocity of light and H the field-strength. With regard to these separations Professor Runge observes:

> Die bisher beobachteten komplizierten Zerlegungen von Spectrallinien im magnetischen Felde zeigen die folgende Eigentumlichkeit: Die Abstande der Komponenten von der Mitte sind vielfache eines aliquoten Teiles des normalen Abstandes "a" $= \Delta\lambda/\lambda^2 = (e/m)\ (H/4\pi c.)$ Sicher beobachtet sind bisher die Teile $a/2$, $a/3$, $a/4$, $a/5$, $a/6$, $a/7$, $a/11$, $a/12$.

In determining the intervals of the substances, I have used the components only of the line in question, and recorded the largest aliquot part of these components as the interval. This process yielded intervals which in themselves are multiples of a small value: e. g., there are intervals $a/11$, $2a/11$, $3a/11$, $4a/11$, $5a/11$, $6a/11$; $2a/12$, $3a/12$, $4a/12$, $6a/12$; $3a/16$, $6a/16$, $9a/16$, $12a/16$, and possibly others. These intervals may be expressed in $a/11$, $a/12$, $a/16$, and the multiple factors correspondingly increased. Professor Runge prefers this method. So far as the comparison of lines is concerned, it is entirely immaterial.

The actual number of intervals is many less than recorded in the tables. A bracket indicates that the intervals 0.53, 0.54, 0.55, and 0.57 may all in reality be the interval $a/2 (= 0.554)$. The greatest

[1] *Physikalische Zeitschrift*, **8**, 232, 1907.

TABLE OF INTERVALS

Interval or Approx. Part of "a"	Multiples of Intervals = "Factors"	No. of Lines Represented	Substance to Which Types Belong	Remarks	λ
	22, 15, 12, 7	1	*Zr*		3459.1
	22, 16, 10, 9	1	*Zr*		4440.8
	13, 7	1	*Zr*		3891.61
0.10 ($a/11$)	15, 13, 11, 2, 0	1	*Ne*		
	20, 16, 14, 12, 8, 8, 4	1	*Hg*	¶ 1, N.II.	3655.
	12, 7	1	*Os*		4420.63
0.12, $a/9$†	7, 4	1	*Yt*		5510.1
	7, 5, 4, 3, 2	1	*Yt*		4235.89
$a/6$ 0.18	10, 9, 8, 7, 6, 2, 1, 0	1	*Ne*		
$a/6$ 0.185					
$a/6$ 0.19	14, 9, 5, 4, 0	1	*Ne*		
	9, 7, 5, 2, 0	1	*Yt*		4398.21
0.20	9, 6, 4, 3	1	*Yt*		4083.89
	7, 6	1	*Yt*		4682.5
($2a/11$)	5, 1	1	*Yt*		4375.11
	5, 2	1	*Yt*		4177.68
	5, 4	1	*Zr*		4004.51
	10, 8, 7, 6, 4, 2	1	*Hg*		
0.21	3, 2	1	*Zr*		3674.98
0.22	9, 7, 3, 1	1	*Yt*		4236.10
	4, 3	1	*Zr*		3894.00
	4, 1	1	*Zr*		3916.16
($a/5$)	8, 7, 6, 5, 2, 1	1	*Ne*		
	8, 5, 4, 3		*Qu. Ag. Al. Tl.*	I. N. S.	
	8, 5, 4, 3	1	*Ba*	I. N. S. *	
	8, 4		*Cu. Ra. Ag. Tl.*	I. N. S. *	
0.25	6, 5, 1, 0	1	*Zr*		4171.65
	6, 1	1	*Zr*	$3a \div 11$ (5, 1)	4256.66
		1	*Zr*		
0.26 ($2a/9$)†	6, 5, 3, 0	1	*Zr*	$a \div 11$ (15, 14, 8, 0)	4258.31
($3a/13$)†	8, 3, 2	3	*Zr*	$a + 11$ (21, 8, ‖)	See *Zr* 6 Comp.
	7, 2, 0	1	*Zr*	$a \div 11$ (18, 5, 0)	4061.70
$a/4$ 0.265	8, 5, 3, 2, 0	1	*Yt*		3584.71
$a/4$ 0.27	6, 5	1	*Zr*	$a \div 10$ (16, 13)	3470.10
	6, 5, 4, 1, 0	1	*Ne*		
	7, 5, 4, 3	2	*Zr*	See *Zr* 8 Comp.	
	3, 2	1	*Zr*		4456.50
0.29	7, 1	2	*Zr*	λ 4003.28 and	3578.40
	2, 1	1	*Zr*		3588.15

TABLE OF INTERVALS—*Continued*

Interval or Approx. Part of "*a*"	Multiples of the Intervals = "Factors"	No. of Lines Represented	Substance to Which Types Belong	Remarks	λ
0.30	5, 2 (?)	1	*Ba*		5971.90
	4, 1	1	*Yt*		3833.10
3*a*/11	4, 1	1	*Zr*		3890.58
	4, 3	1	*Zr*		3568.32
0.305	6, 3, 2, 0	1	*Zr*	*a* ÷ 11 (18, 9, 7, 0)	4093.32
0.32	9, 4, 0	1	*Zr*		4187.30
	5, 2	1	*Zr*		4418.80
0.33	4, 2	1	*Zr*		4034.30
3*a*/10	4, 1	1	*Zr*		4031.57
	2, 1	1	*Zr*		3284.89
0.34	3, 2, 1	1	*Zr*		3396.51
	4, 1	1	*Zr*		3634.33
0.36	5, 3, 1	1	*Zr*		3483.70
	3, 2, 2	1	*Zr*	¶	3482.96
	5, 3, 1	2	*Ba*	H and	
	4, 2	2	*Ba*	2 N. †	
a/3	4, 2	1	*Yt*		3200.04
0.37	3, 1, 0	1	*Zr*		3376.42
	6, 4, 3, 2, 1, 0	2	*Zr*	See *Zr* 11 Comp.	
0.38	5, 3	1	*Zr*		3323.21
	5, 1, 0	1	*Yt*		4477.10
	4, 1, 0	1	*Yt*		3951.76
0.39	4, 3, 2	1	*Zr*		4110.29
	4, 3	1	*Zr*		3434.08
(4*a*/11)	4, 3, 2, 1, (0?)	8	*Hg*	I. N. II. *h*.	3125.80
0.42	3, 2	8	*Zr*		
	3, 1	6	*Zr*	See Zirconium	
	4, 1	3	*Zr*	Quadruplet Table	
	4, 2	2	*Zr*		
3*a*/8	2, 1	1	*Zr*		
0.43	5, 4, 2, 1, 0	2	*Zr*	See *Zr* 9 Comp.	
	4, 3, 2, 0	1	*Zr*		3368.01
	6, 4, 1	1	*Zr*	*a* ÷ 10 (27, 17, 4)	3554.31
	4, 3, 2, 2, 1, 1	1	*Yt*	¶	3818.49
0.48	3, 1, 0	1	*Zr*		5350.50
0.50	5, 6, (1?)	1	*Zr*		3498.00
	3, 1	3	*Zr*	See *Zr* 4 Comp.	
	3, 2, 1, 1, 0	1	*Yt*	¶	3950.51
5*a*/11	3, 1	2	*Yt*	See *Y* Quadruplet	
0.51	2, 1	1	*Zr*		4582.50
	3, 1	2	*Zr*	λ 4429.28 and	4024.20
	3, 2, (?)	1	*Zr*		3480.59

TABLE OF INTERVALS—*Continued*

Interval or Approx. Part of "*a*"	Multiples of the Intervals = "Factors"	No. of Lines Represented	Substance to Which Types Belong	Remarks	λ
	2, 1, 1, 0	1	*Zr*		4055.20
0.54	5, 3, 2, 1, 0	1	*Yt*	I. N. I. S.	4199.46
	4, 2, 2, 0, 0	1	*Zr*		4268.22
0.55	3, 2, 1	1	*Ba*		
	3, 2, 1	2	*Yt*	λ 4358.91 and	3195.80
	2, 1	1	*Yt*		
a/2	3, 2, 1	1	*Zr*		4590.81
	5, 3, 2	1	*Zr*		4431.70
	4, 3, 2, 1, 0	1	*Ne*		
	5, 3, 2, 1, 0		*Hg*	I. N. I. S.	
	5, 2, 1, 0		*Hg*	I. N. II. S.	
	4, 3, 2, 1		*Hg*	2 N. I.	
	4, 3, 1		*Hg*	2 N. II.	
	4		*Hg*	2 N. III.	
0.57	2, 1	2	*Zr*	λ 3934.99 and	3973.68
0.60	3, 2, 2, 0	1	*Zr*		4214.05
6*a*/11	1, 2	1	*Zr*	‡	3454.71
0.63	3, 2, 1, 1, 0	1	*Yt*		3628.89
(3*a*/5) 0.67	3, 1, 0	1	*Zr*	*a* 11 (20, 7, 0)	3501.50
(3*a*/4) 0.83	2, 1, 0	1	*Zr*		4046.30

* *Ba* λ 4166 is just as accurately represented by *a*/4 (6, 4, 3, 2) and *Ra* λ 4436, by *a*/4 (6, 3). Neither of the two systems represents it accurately. Multiples of (*a* 11) represent these lines even better, except for one component.

† Series types, shown by *Na*, *Cu*, *Ag*, *Al*, *Pt*, *Mg*, *Ca*, *Sr*, *Ba*.

‡ The *p*-component lies outside of the *s*-component.

¶ When *p*- and *s*-components are duplicates in position, they are designated by repeating a number.

‖ The triplets of this first adjacent series are 3 and 5 times *a*/5.

deviation, 0.09, is in a fourfold of 0.53. It is advantageous, however, to preserve the factor 0.53 in the tables just as it is. For, if a sixfold or greater factor of 0.53 should be found in any substance, the interval would probably not belong in *a*/2. When the multiple factors are small, wider ranges in the intervals can be regarded as coming under one interval. The inverse is true for large multiple proportions. Therefore one could more readily classify 0.33 (with largest factor equal to 4) under 0.32 (with largest factor 9) than in the inverse manner. However, 0.33 is an aliquot (3*a*/10) of *a*. Taking 3*a*/10 as an interval, the 0.34 (with factor 4) interval is reasonably near it

but the 0.32 interval is near the limit of allowable error. The interval 0.29 is midway between $a/4$ (=0.28) and $3a/11$ (=0.30.) Without material error, it could be classified $a/4$ or $3a/11$. Its factors are not present in either $a/4$ or $3a/11$ and for the present may remain unclassed. The same difficulty arose with 0.21 until further classifying showed the presence of 2, 3, and 4 times 0.21 and that these could be represented by $3a/16$, $6a/16$, $9a/16$, and $12a/16$.

It may be contended that the magnitude of the intervals indicates an irrational part of the normal "a" rather than aliquot parts of such a normal value, or in other words that the "normal" is fictitious. Such a conclusion is possible and if an examination of other substances gives other apparent irrational intervals with numerous and large factors, it will be the more logical conclusion. As soon, however, as one omits the quadruplets, there remain but few lines which suggest this difficulty. With respect to the quadruplets one can very frequently change the interval and at the same time change the factors so that the line is practically just as well represented. Also, with two values, i. e., four components, distinction is difficult, whereas with six and more components the intervals can be determined with considerable sharpness.

Lines with many components have frequently a larger interval which occurs as a common difference in passing from component to component, instead of measuring from the position of the undisturbed component. In neon one finds the *s*-components of λ 6217.5 represented by $\pm$ (14, 9, 5) $a/6$, or a common difference of $5a/6$ repeated four times. The *p*-components of the same line are represented by $\pm$ (5, 0) $a/6$, or $5a/6$ repeated twice more. In zirconium 3459.1 the *s*-components are $\pm$(23, 15, 7) $a/11$ or the distance $8a/11$ occurs four times. For the *p*-components of this line one finds $12a/11$ twice repeated. In yttrium λ 4235.89 the perpendicular components are represented by $\pm$(7, 5, 3) $a/6$, and the parallel components by (4, 2) $a/6$ or the distance $a/3$ is measured eight times in this line. Numerous other cases can be found in the table.

From the examples given one sees that the distance between the adjacent *p*- and *s*-components is much smaller than the distance between the single *p*- or single *s*-components. This smaller distance is naturally more accurately determinable as the number of com-

ponents increases. Then it is evident that the greater separations are always whole multiples of small distances, and also that the distances from the position of the undisturbed component are whole multiples of such a small distance, or "interval."

In the quadruplets, the small interval is more difficult to determine, and they, therefore, have less weight in determining this fundamental question of the rationality or irrationality of the "interval" space. In these quadruplets, however, one sees that the components stand in a simple numerical relation to each other.

The multiples and their intervals remind one of the law of multiple proportions in chemistry.

By means of intervals, their multiples and multiple factors, one obtains a most convenient method of comparing lines and substances. The quadruplet principal series types, which Professor Runge found in *Na, Cu, Ag, Al, Tl, Mg, Ca, Sr*, are represented by $a/3$ (4, 2).

In yttrium there is one line, λ 3200.44, which may possess these values but the companion sextuplet is absent. It may be of type (15, 7) $a/11$. The sextuplet principal series, $a/3$ (5, 3, 1), found in the same substances has a solitary representative in zirconium in the line λ 3483.70, but the companion quadruplet is absent. *Hg* first adjacent series satellite λ 3663.05 is probably represented in yttrium by λ 4199.46. The separations of the components of the yttrium line are a trifle smaller. One line, λ 3624.10, in zirconium is like two lines, λ 4128.49 and λ 3930.84, in yttrium. These lines are 4 and 1 times $3a/11$. Similarly there are five lines in zirconium whose separation is like two yttrium lines and the separations $5a/11$ (3, 1). Among these there is considerable variation from the desired accuracy. These lines are zirconium λ 4429.3, λ 4199.2, λ 4043.8, λ 4024.2, λ 3296.6, and yttrium λ 4475.9 and λ 3449. Zirconium λ 4590.8, barium λ 5997.4, and yttrium λ 3195.8, λ 4358.9 are types of $a/2$ (3, 2, 1). These yttrium lines are the best duplications observed. The most prominent feature of the interval tables is the types (interval times factors) which are only once represented. As before mentioned, it requires four lines to make sure of a series. Hence the table excludes series except in zirconium under the interval 0.42. These lines are unequally distributed in distances (in terms of vibrations per cm).

The intensities are also irregular. The factors, by which the intervals must be multiplied to give the required separation, are very numerous, as well as possessing a variety of combinations. The principal series and second adjacent series of the previously mentioned substances have the interval $a/3$. This interval is represented by eleven lines in yttrium and zirconium, but only in two cases are the factors of proper magnitude and number to produce the series type. This leaves nine new types under this interval.

Under $a/11$, an interval of the *Hg* first adjacent series, and multiples of $a/11$, there are six yttrium, fifteen zirconium, one neon, and one osmium lines, or a total of twenty-three lines. There are some duplicates, which leaves eighteen types, including neon, and these are all different from the type of *Hg* line λ 3665. The interval $a/5$ is well represented in the first adjacent series satellite of *Cu*, *Hg*, *Al*, and *Tl*, but the interval does not enter in right proportions in yttrium or zirconium to form the same types. Some types have the same factors as others with one or more factors suppressed. The question naturally arises, whether these lines may not be duplicates and whether the omission might not have arisen from weakness of the component or inadequate exposure. This may be true in a few cases, but generally it is not for the following reason: The ratio of the intensity of components is known both in the line having all the components and in the line having some components hypothetically missing. A simple mental calculation will then tell whether the missing component, if existing at all, may have been too weak to leave a photographic impression on the plate.

IX. CONCLUSIONS

1. The lines of the triplet class in barium mostly fall into groups with a separation similar to the separation of some components of lines other than triplets.

2. A great majority of all lines, having more than three components, possess underlying simplicity and likeness in the great variety of their separations. This simplicity or similarity is manifested in small magnitudes which are designated by the term "intervals." The components of these lines are obtained by multiplying the intervals by "factors." The intervals themselves may have mul-

tiples. The smallest intervals are aliquot parts of a (where a is the separation of the "normal triplet" as given by Professor Runge). The latter recently found in neon the aliquot intervals $a/2$, $a/3$, $a/4$, $a/5$, $a/6$, $a/7$, $a/11$, $a/12$. All, except $a/12$, are observed in the present experiment.

3. The great variety in the magnetic separations arises principally from the variation both in number and in magnitude of the interval factors. The product of interval and factor or combination of factors gives the types of separation.

4. The interval 0.37 ($=a/3$) times (4, 2) and (5, 3, 1) gives respectively the quadruplet and sextuplet principal series and second adjacent series found by Professor Runge in *Na*, *Cu*, *Ag*, *Al*, *Tl*, *Mg*, *Ca*, *Sr*, *Ba*, *Ra*. The quadruplet has one doubtful representative in yttrium, and the sextet one line in zirconium. However, the same interval combined with factors in other proportions gives nine new types. One of the *Hg* first adjacent series types has a solitary representative in these substances, but the intervals yield at least 18 new types.

5. The substances yttrium and zirconium yield a great number of new types.

6. The most prominent characteristic of the numerous new types is the number which are unrepeated in the spectral range of these experiments. It would be interesting to extend the measurements far into the ultra-violet with a much stronger field to see whether there are not more repetitions and even series.

7. The interval (0.42 [$=6a/16$]) in zirconium is the only one which would promise series types. There are eight quadruplets of one type and six of another, but no series found.

8. There are six lines in yttrium like seven lines in zirconium and these are represented by three types. This is scarcely enough terms to suggest similarity of the substances. Chemically, however, there is a similarity. The substances are parallel terms in two adjacent (third and fourth) Mendelejeff's groups.

9. The one quadruplet of osmium has an interval of the first adjacent series, but it is not of the latter type.

10. An investigation of triplets for series is always tedious. Dividing them into groups, as in barium above, is advantageous frequently. They then look like other types with suppressed components. But

in yttrium and zirconium one would be at a loss to know which type had the component suppressed. This would suggest that a given separation in such triplets may represent more than one type. The investigation of yttrium triplets for series has been reasonably complete and negative. In zirconium, time has permitted the study of only a few triplet magnitudes. The results have been likewise negative. The triplet values are extended over a large range. They do not collect around a "normal separation" or multiples of aliquot parts of a normal separation.

11. Lines with no components (unseparated) in zirconium show no series. Most of these lines are probably unanalyzed types.

12. There are a great many lines which may be associated in pairs. Such lines are comparatively near each other on the scale of vibrations. The pairs may have the same separation or not, and have the same or a different number of components. In substances which have yielded series, such pairs are frequently conspicuous. These pairs repeat themselves in other parts of the spectrum with considerable uniformity of separation. In osmium repetitions are not present, and in yttrium and zircon only apparently so since the separations of the prospective pairs are very irregular.

X. GENERAL CONCLUSION

There is a general dissimilarity between the lines of yttrium and zirconium; and between these lines and the lines of all substances which have yielded series. But all substances have common fundamental intervals of small magnitude, and few in number, intimately connected with a "normal separation."

In conclusion I wish to thank Professor Voight of the University of Göttingen, Germany, who suggested this investigation and kindly placed the resources of the Institute at my disposal, for his friendly assistance, and enthusiastic encouragement. Likewise I acknowledge my obligations to Professor Runge of the same university, whose invaluable experience in spectral work was courteously given to me.

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ON THE SENSITIVENESS OF PHOTOGRAPHIC PLATES AT DIFFERENT TEMPERATURES

By ROBERT JAMES WALLACE

In 1895 Abney investigated the effect of temperature upon the sensitiveness of photographic plates, and gave his conclusions in an address before the Royal Photographic Society.[1] His methods and results may briefly be summarized as follows: a special box constructed so that its temperature could be varied by means of a freezing mixture or a "heated brick" contained the plate under test. When at the determined temperature, exposure was made through a square aperture, moving along a slot in the lid, to a small Argand paraffin, or amyl acetate lamp. From measurement of the plates thus obtained, where the light was constant and the exposure varied, this investigator found that there was "not necessarily any variance in the gradation of the curves—but that the rapidity is altered—although not to the same degree, for each kind of plate," being invariably less as the temperature is reduced. With constant exposure to light of varying intensity, he also found that with exposures made above 33° C. the gradation changed, the curve becoming steeper, although up to this temperature the heat had no other effect upon the plate beyond making it more rapid. In this latter portion of the work, the light used was not exactly the same in the hot and cold experiments, exact values not being aimed for, but merely the change in gradation.

Later, E. S. King, of Harvard College Observatory, also made some experiments upon the influence of temperature upon sensitiveness,[2] and exposed two portions, cut from the same plate, to temperatures of "about 0°," and "about 80°," obtained by placing one out doors, and the other over a hot-air "register" until the plates had taken the temperature of their surrounding air. They were then exposed for one minute to the extra-focal image of *Polaris* in the telescope. In the case of the cold plate the "focus was set to reduce

[1] *Action of Light in Photography*, Sampson Low, Marston & Co., London, 1897.

[2] "Photographic Photometry," *Photo-Beacon*, **17**, 267, 1905.

the light by one-half magnitude." It was found on development that the images were of similar density, showing that "the difference in sensitiveness for a change of about 70° or 80° is 0.5 magnitudes, the cold plate being the more sensitive." From further experiments it "was found that temperature not only affected the sensitiveness of the plate but also changed the gradation of the intensities of darkening."

When the results of these investigators are compared they are almost directly opposed to each other. The work presented in this paper was therefore undertaken in the hope that a greater concordance might be obtained by working under definite conditions.

METHOD

The plan of work will first be noticed, as it will assist in the clear understanding of the results. Plates were exposed in a temperature-box constructed for this purpose, somewhat similar to that used by Abney, at temperatures varying from +100° to −14° C., and were developed and fixed under precisely similar conditions. Another series of exposures under natural conditions of temperature, and varying from +24° to −14° C. was made to corroborate the laboratory results with artificial temperatures. The negatives thus obtained were measured with the spectro-photometer especially constructed for such work, and detailed in a former paper,[1] and curves were plotted showing the relation between exposure and density for each variation in temperature.

TEMPERATURE-BOX

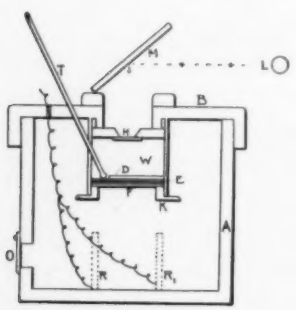


FIG. 1

The design of the temperature-box will be understood by reference to the plan which is given herewith (Fig. 1): *A* is a zinc-lined box about 12 inches square, closed by the light-tight lid *B*, which carries with it the cubical plate-chamber *W*. This chamber contains a transparent scale-plate *D*, which rests in contact with the surface of the sensitive plate *E* under test. This sensitive plate is

[1] *Astrophysical Journal*, **25**, 124, 1907.

held in position by means of a light wooden frame *K*, in which is fitted a piece of deep-ruby glass *F* to avoid action from scattered light inside the box *A*. Light is obtained from an acetylene burner at *L*, and reflected down by means of the mirror *M*, through the ground-glass *H*, and thence passes to the sensitive plate. A thermometer *T* is inserted so that its bulb rests in contact with, and presses against, the sensitive surface. Increase in temperature is obtained by leading the 110-volt direct current through the two resistance coils *RR'*, which run the entire length of the box. For reduction in temperature many experiments were made with various freezing mixtures, and also with ether spray and liquid air, which were introduced at *O*.

The scale-plate used was a negative strip developed from an exposure to the revolving sector-disk machine. The method of exposing through a transparency was selected as being most desirable, as by this means there is obtained a constant exposure to light of variable intensity, thus duplicating the conditions under which one works in the case of exposure at the telescope, or in general camera work. The dimensions of the transparent portions of this scale-plate measure 6.5×2.7 cm, while the plates used were 8×10 cm. The use of the sector-disk machine itself would have been still better, but the impossibility of making use of it without practically rebuilding it, led to the abandonment of the idea.

LIGHT

The light used was acetylene, prepared in a Colt generator of water-to-carbide type, and burning from a $\frac{1}{2}$-ft. Halm burner, under a uniform pressure of $2\frac{5}{8}$ inches of water. In front of the flame, and separated from it by a distance of 11 mm, a metal plate is supported from a cylindrical metal chimney, this plate being pierced with a circular aperture of 2.5 mm diameter. This aperture is at such a height that its position comes immediately in front of the center of the white portion of the flame. The burner is fed with gas which passes from the generator, and then through a large bottle containing *KOH;* a manometer indicates the pressure.

If (as has been pointed out by previous writers) care be taken not to turn down the flame at the burner, but to cut off the gas supply abruptly, this arrangement forms an exceedingly good inten-

sity standard, in cases where the spectral quality is suitable. In the present work no compensation color-filter was made use of, as the spectral distribution of the light intensity was of no moment, and was used with similar plates throughout. Generators of the carbide-to-water type are unsuited unless equipped with some form of pressure governor.

PLATE, EXPOSURE, DEVELOPMENT, AND PRECAUTIONARY MEASURES

As the primary object of the investigation was its relation to the photography of faint celestial objects, only one make of plate was experimented upon, viz., "Seed 27 Gilt Edge," which was selected because of its uniformly greater speed.[1] The exposures were made by first dividing them into three groups according to the temperatures, as follows:

A. From +24° C. to +100° C.
B. From +24° C. to −14° C. } (Laboratory exposures)
C. From +24° C. to −14° C. (Outdoor natural temperature exposures)

In the actual handling of both groups A and B, separate sets of plates, all of similar emulsion number, were exposed at each of the following temperatures: (A) +24°, 50°, 75°, 85°, 90°, 95·5°, and 100° C., and (B) +24°, 10°, −2°, and −10°. Besides, several 8×10 plates were cut into six pieces, and the resultant smaller sizes were exposed similarly, care being taken that each plate of the sets of six was exposed at a different temperature, thus assuring direct comparison with each other.

The exposure given each plate was carefully kept constant in all save the actual temperature of the plate itself. The distance of the flame-diaphragm from the center of the mirror *M* was 36 inches, and the duration of exposure was 3 minutes, accurately timed by means of a stop-watch.

During exposure of any one group, the plates were removed from the temperature-box, numbered, and laid face up in an empty plate-

[1] Since the above was written Messrs. Lumière have introduced a special "Σ" emulsion, which from measurements by the writer give a speed increase of 2.3 times that of the Seed "27." This Σ plate, however, cannot be used *generally* in astronomical work, as the grain is 1.7 times larger than that of the "27." The Σ plate also fogs badly in development.

box for a few minutes, until they had assumed the temperature of the room, and then replaced in their original box until all of the units of that group were completed.

Each set of plates was developed at the same time, the reducing agent being Rodinal, which was used at a dilution of 1:24; the temperature of development was 20° C., and the length of time 3 minutes. Some few of the sets were purposely developed for a shorter time—down to 1 minute 30 seconds—in order to make certain that a difference in γ would not affect the general result. In every case the plates were first soaked, immediately before development, in a large quantity of distilled water (temp. 20°) in order to insure the certainty of equal temperature for each plate.

In the case of the plates exposed at reduced temperatures, by the aid of freezing mixtures of ice and salt, etc., the exposure of the plate for some time in the box, to enable it to assume the necessary temperature, gave rise to the idea that the presence of so much aqueous vapor might give disturbing results, even although the plate itself, by reason of its position in the inner chamber, seemed to be protected therefrom. However, the action of water vapor was investigated in the following manner: A $3\frac{1}{4}\times 4\frac{1}{4}$ plate was cut into two strips, one of which was soaked in distilled water for 3 minutes, and then removed, drained, and placed in the plate-holder side by side with the dry slip, and both were immediately subjected to simultaneous exposure. Both plates were then soaked in water and developed.

Examination during development shows that the image appears with equal rapidity on both strips, but as development progresses the "dry" strip becomes apparently more dense. Examination of the fixed and dried negatives confirms this greater density. Measurement of the plates furnishes data for the construction of the accompanying curves (Fig. 2) from which it will be seen that the general speed is reduced by $2^{\circ\cdot 5}=1.4$ times; the curves, however, do not cross, but appear to be shifted along the log E axis and parallel to it. From the temperature-curves, which will be shown presently, it will be seen that aqueous vapor (if present) therefore does not alter the result. This experiment was several times repeated, for varying times of preliminary immersion, with uniform results.

Any disturbing influence of the ether vapor upon the sensitiveness

was also investigated, but with negative results: even bathing in sulphuric ether appears to have no effect upon either D or γ_∞.

In the course of the work it was also necessary to determine the influence of soaking in water prior to development, as some of the

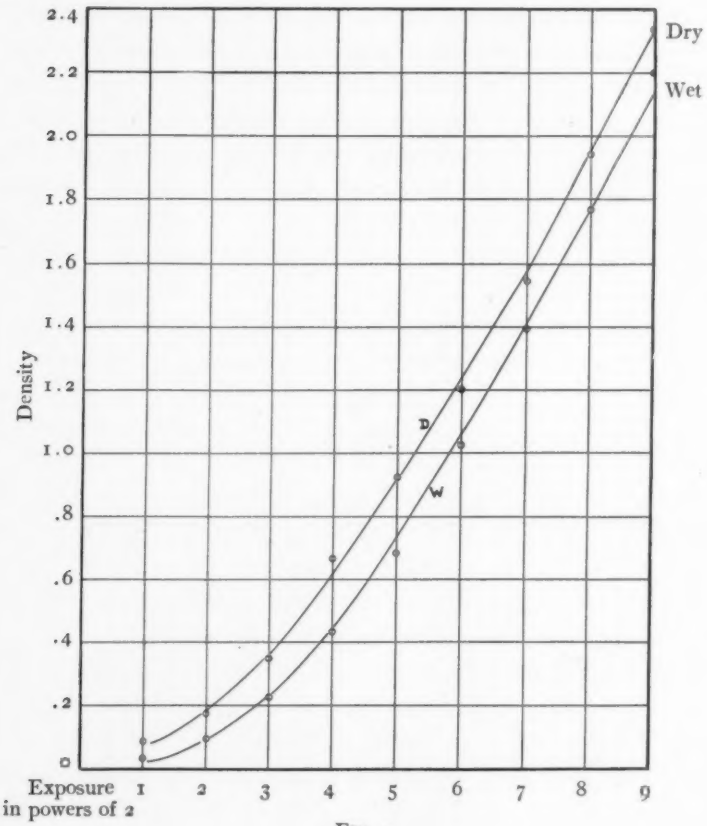


FIG. 2

test plates were developed without this initial soaking. Experiments upon a sector-disk exposure, where the plate was cut in half before development, and one portion soaked in water, showed, when both parts were developed together, that the image appears first upon the dry half and seems to have greater vigor. As development progresses, the wetted plate rapidly overtakes the other and (by ruby light) soon no difference is discernible. Measurement of the plates, however,

confirms the results arrived at by Mees and Sheppard, viz., the wetted plate has a higher γ, and is likewise shifted along the log E axis,[1] but this does not influence the temperature test results.

Fourteen duplicate sets of plates completed the laboratory experiments, of which eight sets were of Group A. Preconceived opinions held by various observers regarding the influence of temperature upon sensitiveness necessitated verification of the laboratory results by exposures made at duplicate temperatures under natural conditions. For exact quantitative work exposure at the telescope on "extra-focal" images could not be considered, as uniformity of photographic light intensity is impossible; for, while an experienced observer is able to detect a certain amount of atmospheric "thickening," yet he

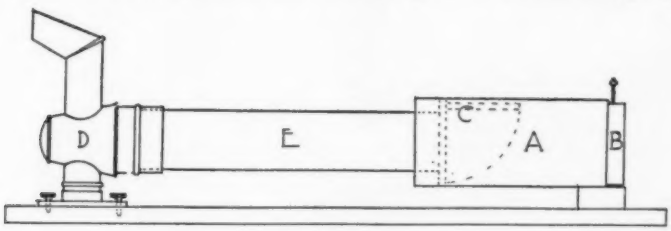


FIG. 3

cannot make any reliable measure of the same, nor can he say what absorbing influences are present at any time during the work, particularly in the more refrangible wave-lengths, the region of greatest photographic activity.

For this reason, therefore, a separate arrangement was made which is shown in outline in Fig. 3. *A* is a rectangular wooden box into which fits the plate-holder *B*, while a flap-shutter, *C*, controls the length of exposure. Light is supplied from the constant acetylene burner at *D* (this burner being the same as was used for the laboratory tests). The light was used at a constant distance of one meter from the plate surface, and fits "light-tight" into the end of the brass tube *E*.

In practice the scale-plate (which was the same as used in the foregoing experiments) was placed in contact with the sensitive plate in the plate-holder. The entire apparatus and the plates intended for use were placed out-doors in the open air some hours prior to

[1] *Journal of the Royal Photographic Society*, **47**, 88, 1907.

their exposure, and arrangements were also made for changing plates out-doors. As a rule, six exposures were made out-doors at low temperature, followed by six exposures in the laboratory at "normal" temperature. Altogether, Group C covered eleven sets of plates, averaging four to eight plates to a set. As with Groups A and B, each set of Group C was developed at one time, under constant conditions as previously described.

The laboratory experiments connected with this work were begun in the early part of 1906, but the natural temperature verifications could, of course, be performed only during the winter months, and were conducted at various times during 1906–7 and 1907–8. These past two seasons have not been characterized (at this location) by very low temperatures, but sufficient data have been obtained to give almost uniformly concordant results.

METHOD OF RECORDING RESULTS

When all of the principal plates had been measured in the photometer, the densities for each of the plates corresponding to similar temperatures were combined, and a mean was obtained. This tabulation showed a good agreement between each of the plates, there being no error greater than that which could be ascribed to the local variations of the plate coating. It is not necessary that these results be given *in extenso*, but Table I gives an example which may serve well as a specimen.

TABLE I

Plate	Measured Density of the Corresponding Strips								
	1	2	3	4	5	6	7	8	9
A.....	0.0719	0.3642	0.8632	1.3019	1.6441	1.8064	2.1117	2.4012	2.5312
B.....	.0691	.3819	.8679	1.2729	1.5262	1.8756	2.1149	2.2921	2.4160
C.....	.0712	.3687	.8855	1.2100	1.5037	1.8621	2.0980	2.2115	2.4322
Mean ..	0.0707	0.3716	0.8722	1.2616	1.5580	1.8480	2.1082	2.3016	2.4598

The mean densities thus obtained, when plotted on squared paper, with the density as ordinates, and the abscissae as exposures, give the sensitiveness-curves for the temperatures considered. Fig. 4 shows the curves of temperatures +24° to 100° C., while Fig. 5 shows the effect of reduction from +20° to −20° C.

RESULTS

In these curves representing temperature increase, it will be noted that between the temperatures of 24° and 75° the curves cross one another: this is the "alteration in gradation" spoken of by

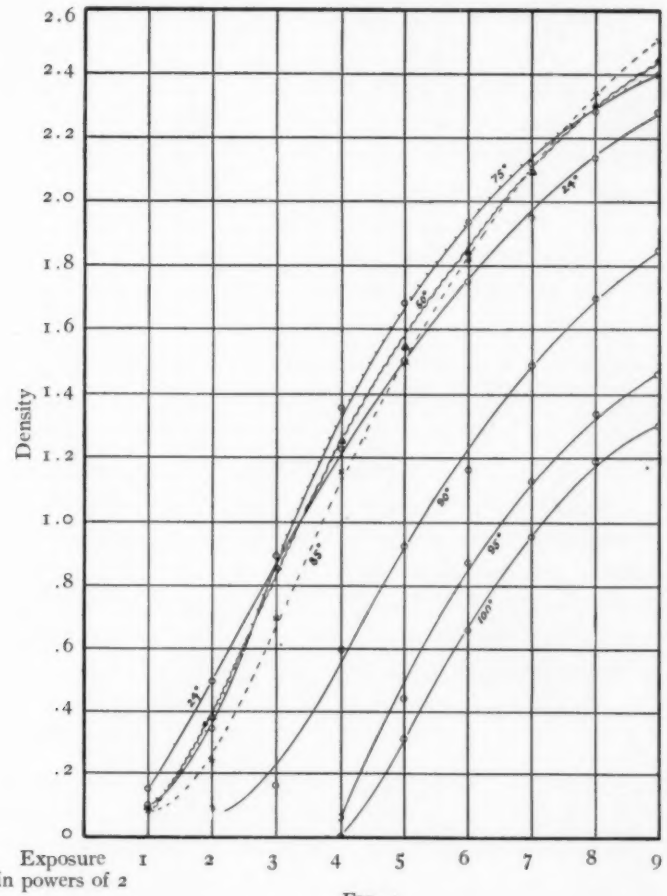


FIG. 4

both Abney and King. In the opinion of the writer it is this "alteration" which accounts for the discordance between the findings of these workers. According to Abney, *increase* in temperature results in added speed, while according to King, greater speed, even to 50 per cent., is obtained by a *decrease* in temperature. In reality

then, it simply depends upon which portion of the curve is taken as to whether the speed is increased or reduced, i. e., whether one considers faint objects with consequent low photographic densities, or bright objects with full exposure and consequent high densities.

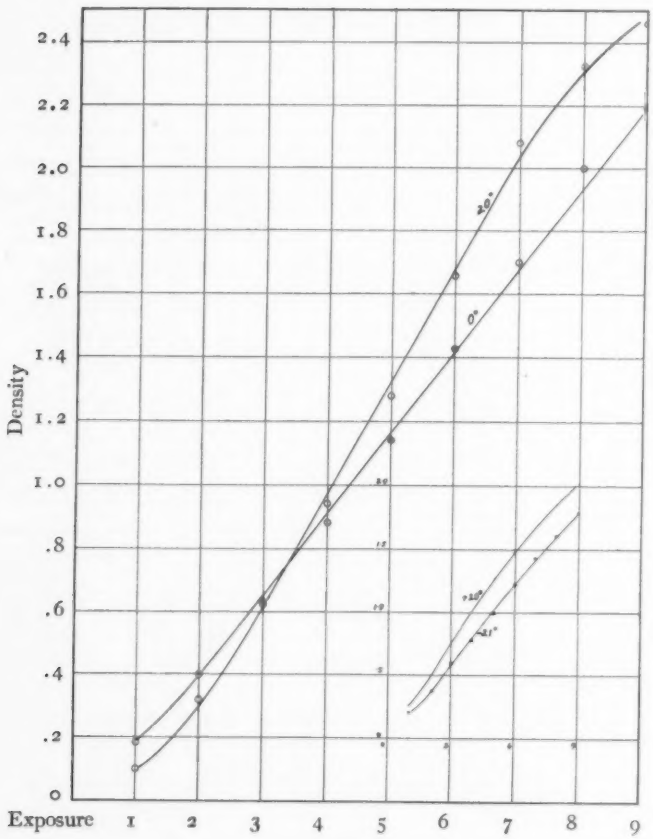


FIG. 5

In the negatives obtained, the development was such that the "straight portion" of the characteristic curve embraced about five magnitudes. As the densities of a photographic negative throughout this "straight portion" are proportional to the logarithm of the light received, then it is sufficient to multiply D by 2.5 in order to convert it into stellar magnitudes. Such magnitudes, however, will

not be absolute, but merely relative, as they are based upon the light used in the course of the investigation, and will vary according to the initial intensity, for, as is well known, the photographic plate does not follow a straight-line law with reference to intensity.

Thus, from this point, where the curves cross, the plate becomes slower for fainter stars as the temperature is increased, while under the same conditions the plate is faster for the brighter stars. Beyond a temperature of 85° C. the plate breaks down, and a considerable amount of fog is induced,[1] which increases very rapidly with a further slight rise, until at 100° C. it is very heavily veiled and badly mottled. Measurement of the plates taken at this temperature presented considerable difficulty. The actual "fog value" of each plate was, of course, subtracted from the densities before plotting.

Taking the case of the curves representing the plate values for the temperatures of 24° and 50°, we see from the mean separation of the curves $D_{0.4}=0.06$, which amounts to 1.04 times less chemical light action on the heated plate than on that at normal temperature, for the fainter stars; while on the other hand, for $D_{2.2}=0.95$, the action is increased 1.9 times. Between 24° and 100° the mean difference is $2^{3.5}$, or 11.3 times general reduction in speed.

The original scale-plate and the negatives therefrom, possess nine separate shades or tone-values, and defining them from the weakest to the most opaque as $D_1, D_2, \cdots\cdots D_9$, we may carry the method of recording results a step farther and re-plot each in terms of D_n and temperature, and thus afford a rapid connection to everyday routine work. Such a series of curves is shown in Fig. 6.

In the preparation of this figure, all of the curves from "normal" (+24° C.) to +100° C. were first plotted and then all of the values of D for temperatures lower than +24° were reduced to a mean D for each point, and shifted vertically to connect. As has already been stated, the magnitude value of the change in D_n with temperature cannot be referred to an absolute scale, because in quantitative photographic astronomical work, the value of the intensity recorded is dependent upon (*a*) the atmospheric absorption, tremor, etc., and (*b*) the length of exposure. Care with reference to the development

[1] Accompanied by reversal in the lower values of D.

constants eliminates these (relatively) so that to consider the star image in terms of D_n it simply remains to read off the corrections necessary for temperature.

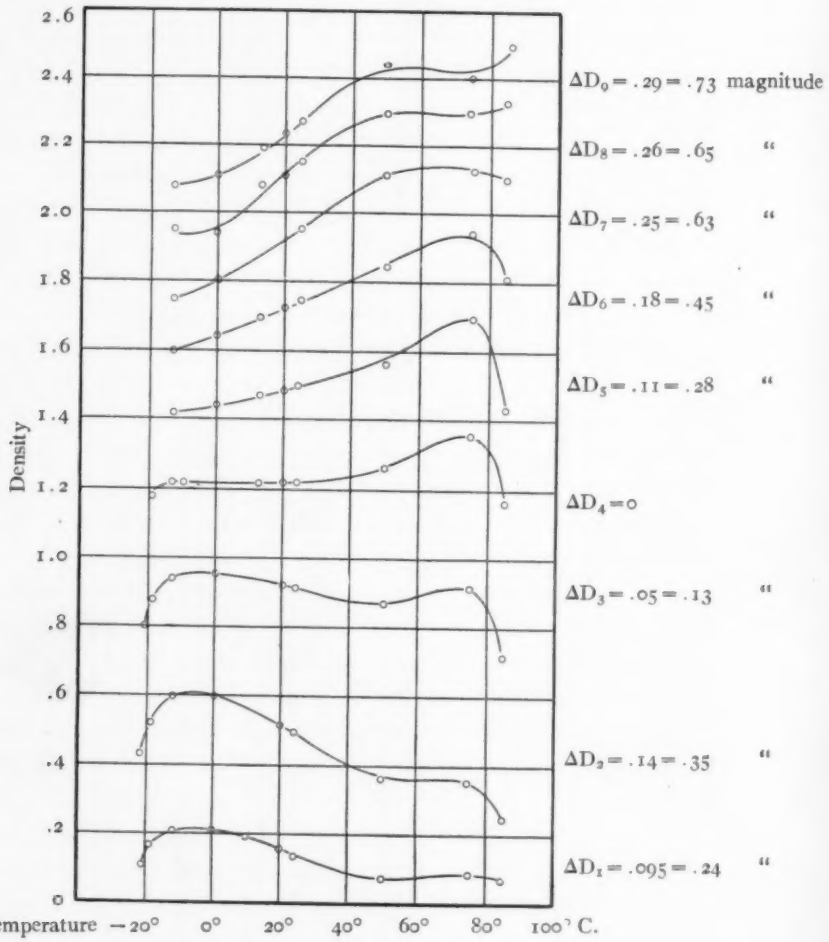


FIG. 6

Broadly considered, it may be stated that for images at about the minimum of photographic action, the sensitive plate is faster by about 0.35 magnitude in a temperature range of from −18° to +32° C. (0° to +90° F.) and for the high values of D (corresponding to the brighter stars) about 0.7 magnitude slower, while

for stars of medium density (corresponding to a value of about $D=1.2$) there is no apparent change.

From the examination of the measurements and curves of this entire series of plates, the writer is forced to the conclusion that there is a limited range of temperature at which this added D value for light of low intensity is apparent, and that at other temperatures, either above or below this region, the sensitiveness-curve falls rapidly and smoothly. In other words, photographic sensitiveness plotted against temperature may be represented by a curve similar to the probability curve. This idea is borne out when we consider the curves already shown, where, in the higher temperatures, there is a certain point above which the plate curves fall off from the normal and are moved bodily along the log E axis; precisely the same effect is indicated in the case of temperature reduction curves representing successively lower temperatures. This is to be expected when consideration is given to the classic experiments of Dewar, who showed that there was a very great decrease in sensitiveness at temperatures about $-200°$ C. The influence of temperature upon general velocity reactions would also point to a similar conclusion.

The points dealt with in this work require extension with special apparatus, by (preferably) other investigators, at temperatures intermediate to $-10°$ C. and $-200°$ C., as it would be desirable to acquire data relative to the formation of the rising branch of the curve. It should also be pointed out that it by no means follows that the region of maximum is identical on plates of different chemical constitutions, or that difference in wave-length may not modify the conclusions arrived at.

YERKES OBSERVATORY
April 28, 1908

THE RELATION OF LIGHT OF VERY SHORT WAVE-LENGTH TO SOME VACUUM TUBE PHENOMENA

By THEODORE LYMAN

Schumann has observed that the radiation which comes from the neighborhood of the cathode in a vacuum tube is particularly rich in light of very short wave-length. The writer began the present investigation for the purpose of ascertaining if these most refrangible rays were confined entirely to the region near the negative electrode. Such an inquiry is of some interest for two reasons. First, from the practical standpoint, it is important to know the distribution of light within a vacuum tube in order that the tube may be given the best shape for the purposes of spectrum analysis. Second, from the theoretical standpoint, it is important to ascertain the relation of the sources of light of short wave-length within the tube to the points of luminosity, because of the bearing of this relation on the theory of electric conduction and radiation in gases at low pressures. The first few pages of the paper are taken up by a description of experiments on this subject.

The latter half of the paper relates to the part played by light of very short wave-length in producing ionization within a discharge tube. That some kind of radiation acts to increase the conductivity in the electric discharge at low pressures has been proved by J. J. Thomson; and the effect has been attributed by him to the influence of the *Entladungsstrahlen* discovered by Wiedemann. One of the objects of the present paper is to show that in all probability the active agent in producing ionization is not a new form of radiation but light of wave-length shorter than λ 1800. The argument is based on the recent work of Mr. Frederic Palmer and upon the writer's observations on the relative efficiency of various sources in producing the most refrangible rays. The subject naturally leads to an inquiry into the nature of *Entladungsstrahlen* themselves, and the last part of the paper will be found to contain some suggestions on this question.

In attacking the problem of the distribution of light in a vacuum tube the ozone-producing action of the most refrangible rays has been

employed. It has recently been shown[1] that in the neighborhood of λ 1800 this action increases very rapidly with decrease in wave-length, to such an extent in fact that the discoloration of potassium iodide starch paper forms a good test for the presence of the most refrangible rays. The shape of the discharge tube employed in the present experiments was suggested by an apparatus used by H. A. Wilson[2] in an investigation on a different subject. Two circular aluminum electrodes, 2.3 cm in diameter and 14.5 cm apart, were joined together by a light glass frame and were connected to the terminals of a tube, 52 cm long and 3.5 cm in diameter, by coils of wire. A bit of soft iron at *A* (Fig. 1) permitted these electrodes to be moved

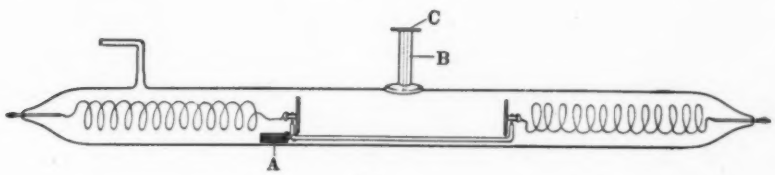


FIG. 1

to any position in the containing vessel by the use of an electro-magnet external to the apparatus. A piece of capillary glass tube *B*, 2.5 mm in bore and 4 cm long, served as a diaphragm through which the light under investigation must pass before reaching the test paper. As the writer has pointed out, it is necessary that this paper be in close contact with the fluorite window *C*, for it if be removed to the distance of even one mm, the absorption of the air for the light of short wave-length is sufficient to reduce the ozonizing action to such an extent that the paper will not respond to it in a reasonable time. The tube was excited by a section of a storage battery giving a difference of potential of 1700 volts; the current, which was controlled by a suitable external resistance, was read by a Weston ammeter, the potential difference was determined by a Braun's electrostatic voltmeter.

Hydrogen is known to give a strong spectrum in the region discovered by Schumann. The first experiments were accordingly made

[1] *Astrophysical Journal*, **27**, 87, 1908.

[2] Thomson, *Conduction of Electricity through Gases*, p. 530.

with this gas. The exhaustion of the tube was carried to the point where the discharge showed its different luminous portions clearly separated.

The manner of making the experiment was as follows: The electrodes were moved until the part of the discharge to be investigated came directly under the capillary opening *B*, a bit of test paper was then placed on the fluorite window and exposed to the action of the light for five minutes. The test paper was then removed and examined and a fresh bit put in its place. This operation was repeated four or five times, the conditions of pressure, current, and position being kept constant. The electrodes were next moved so as to bring another part of the discharge under the window and the operation was repeated. In this way the whole length of the discharge tube was explored. Experiments of this kind were carried out with pressures of 3, 2½, 2, and 1 mm; the current had always the same value, 0.01 ampere.

The results for hydrogen may be summed up by saying that the positions of the sources of the light of short wave-length coincide with the places of luminosity in the tube, and that the intensity of the most refrangible radiation may be judged by the intensity of the luminosity. Thus the starch paper shows some slight effect directly over the cathode, little effect in the Crookes dark space, a maximum effect at the head of the negative glow, no effect in the Faraday dark space, a feeble effect throughout the length of the positive column, and a fairly well-marked effect very near the anode. As long as the pressure has such a value that the luminosity of the negative glow is concentrated in a small volume the effect remains strong. When the pressure decreases and the negative glow begins to spread, the effect seems to decrease with decrease in the intensity of the luminosity.

A series of experiments similar in every way to those just described was next undertaken with air. The writer during his spectroscopic researches has been unable to obtain any evidence of radiation from nitrogen or oxygen in the region of light more refrangible than λ 1800. The light of short wave-lengths which is usually emitted by air in a vacuum tube is due to the presence of some impurity, probably carbon monoxide. It was to be expected, then, that if precautions were taken to exclude this impurity as far as practicable—for to exclude it

entirely is almost impossible—the effects to be observed in air would be much less marked than those recorded in the case of hydrogen. This proved to be the fact, for with pure air in the tube no discoloration of the test paper could be detected at any point in the discharge with an exposure of five minutes.

In spectroscopic work the writer has been accustomed to use a discharge tube of the internal capillary type.[1] In this form of apparatus very little of the light which comes directly from the cathode is able to reach the slit of the observing instrument. It is of interest, therefore, to see if a tube of a different form might not yield better results. Some experiments were undertaken, accordingly, to compare the action of an arrangement like that shown in Fig. 2 with the behavior of a tube of internal capillary type. As far as can be judged from the starch paper test, the results are in favor of the older form of apparatus. For if *B* is used as a cathode and if the current is kept constant, a far feebler discoloration results in half a minute with the new tube than is produced in a like time with the older arrangement. It appears, therefore, that, for practical purposes, the concentration of the current and hence of the luminosity in the capillary more than offsets the greater effect which is found near the cathode.

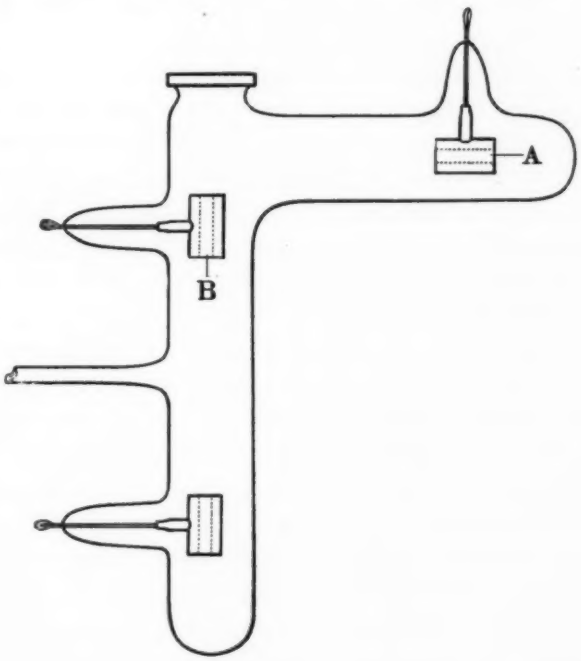


FIG. 2

[1] *Astrophysical Journal*, **23**, 192, 1906.

If the tube shown in Fig. 2 is filled with air it becomes obvious that though the phenomena under discussion are much less marked in this gas than in hydrogen, yet they still exist. For when A and B are used as electrodes and a current of 0.01 ampere is sent through the tube, a considerable discoloration of the test paper results in two minutes, and this effect is greater when B is cathode than when the connections are reversed.

The relation of the distribution of light of very short wave-length to the theory of electric conduction in a vacuum tube depends on the property of producing ionization which the more refrangible rays possess. Mr. Palmer has recently stated that light of shorter wave-length than λ 1800 produces considerable ionization and that this action increases with decrease in wave-length. The general effect can be demonstrated by a simple experiment. A discharge tube of the internal capillary type is filled with hydrogen to the pressure of 2 mm and closed by a fluorite window. A current of say 0.01 ampere is sent through the tube and the air from directly above the fluorite window is blown against a plate connected to a charged electroscope. The electroscope rapidly loses its charge. If now the fluorite window be protected with a piece of microscope cover glass about 0.2 mm thick and if the air be blown to the plate as before, the electroscope will retain its charge unaltered except for its normal rate of leak.

Professor Thomson[1] has shown by direct experiment that the radiation from a spark increases the conductivity of gases. He found that the effect was greatest at pressures of a few millimeters of mercury, and that it was most marked when the discharge took place in hydrogen. He also found that when the actions of different parts of the discharge were compared the effect followed the luminosity, with a maximum near the cathode.

Professor Thomson considers the ionizing radiation to be identical with the *Entladungsstrahlen* discovered by Wiedemann and, therefore, of a distinctly different nature from light of very short wave-length. The writer cannot altogether agree in this point of view, for it does not seem to him necessary to introduce a new form of radiation to account for the observed phenomena. The conditions under which Professor Thomson obtained the largest ionization effects are the very conditions under which light of very short wave-length is most readily produced.

[1] *Proceedings of the Cambridge Philosophical Society*, 10, 74, 1899.

This subject very naturally raises the question as to the nature of the *Entladungsstrahlen* themselves. The writer has repeated the very striking experiments tried by Wiedemann and by Hoffman at atmospheric pressure, and his results and conclusions are identical with theirs. There is a "something" which comes from a spark discharge totally different in character from light of very short wave-length, which produces strong thermo-luminescence in certain mixtures of $CaSO_4$ and $MnSO_4$. To this something the name of *Entladungsstrahlen* has been given.

In case of the experiments tried at pressures much less than atmospheric the writer can no longer agree entirely with the opinions of the earlier investigators. Hoffman[1] states that at low pressures the spark in hydrogen sends out something which is able to penetrate fluorite and quartz and to produce thermo-luminescence. This is in strong contrast to the action of a spark in air, for then fluorite and quartz are very opaque to the new radiation. Hoffman explains the result by supposing that the fluorite sends out secondary *Entladungsstrahlen*. A far simpler explanation is, however, at hand, namely, that the agency which produces thermo-luminescence at low pressures is fundamentally different from that to which most of the effect is due at high pressures; for at low pressures the action of light of very short wave-lengths becomes important. Wiedemann and Hoffman very justly remark that their mixture of $CaSO_4$ and $MnSO_4$ is not sensitive to ordinary ultra-violet light; they were not aware, however, that their test compound is very sensitive to light of the shortest wave-lengths. The fact can be easily proved, however, by placing a specimen, prepared exactly as described by Hoffman, on the fluorite window of a discharge tube. With hydrogen in the tube and a current of about 0.01 ampere an exposure of one second is enough to produce strong thermo-luminescence in the specimen. If, however, the fluorite window is separated from the specimen by a cover glass about 0.2 mm thick, no result at all is produced even after a two-minute exposure.

It seems not unreasonable to suppose, therefore, that where the conditions are suitable for the production of light of the shortest wave-lengths some of the thermo-luminescent effects may be ascribed

[1] *Wied. Ann.*, **60**, 269, 1897.

to their action. The phenomena attributed by Wiedemann to *Entladungsstrahlen* alone are thus in all probability due to the result of two agencies: One, the *Entladungsstrahlen* proper, whose effect is most marked at atmospheric pressure; and the other, light of very short wave-length, whose effect is most pronounced in vacuum tube experiments. It is not impossible that both these agencies act to some degree at all pressures. At atmospheric pressure the *Entladungsstrahlen* are the important factor, though light effects do exist, as may be proved by focusing the light from an aluminum spark on the thermo-luminescent substance by a quartz lens. At low pressures light of short wave-length seems to be the more important factor, though the presence of some *Entladungsstrahlen* cannot be disproved.

Very recently de Broglie[1] has pointed out the existence of an ultra-microscopic dust which always accompanies the spark discharge. The erosion of the $CaSO_4$ surface under the spark suggests the idea that perhaps the mechanism of the *Entladungsstrahlen* depends on a sand-blast action in which this dust plays an important part.

In conclusion, to return to the phenomena of electric conduction through gases, it is extremely probable that the production of light from that part of the spectrum discovered by Schumann plays a distinct rôle in the mechanism of conduction. The importance of this rôle will obviously depend on the amount of light of short wave-lengths produced and upon its absorption by the gas itself. Thus the magnitude of the effect will vary greatly with the nature of the gas and will be larger for hydrogen than for most other gases. This agency adds a new factor to a system already sufficiently complicated. However, the idea of the ionizing influence of radiation has already been used by H. A. Wilson in constructing a theory of the mechanism of electric conduction in a vacuum tube.

Finally, it is of some interest to observe that the same general mechanism gives rise to visible radiation and to the vibrations of the highest known period, for wherever there is luminosity in a discharge tube there also light of very short wave-length is to be found.

JEFFERSON PHYSICAL LABORATORY
HARVARD UNIVERSITY
May 1, 1908

[1] *Comptes Rendus*, **146**, 624, 1908.

OBSERVATIONS ON THE STRUCTURE OF THE ARC

By W. B. HUFF

Several years ago the writer published in this *Journal*[1] a brief account of a spectroscopic study of the structure of the arc. A flat grating was used to give a series of images of the entire arc used as a source of light, no slit being employed. The results showed a marked difference between the parts of the arc. For small currents, the discharge at the negative pole took the form of a stream of light arising from a small area on this pole and spreading out into a cone as it approached the positive pole. The dispersed image of this stream showed that it was due to the metallic constituents of the commercial carbons used as terminals. The bands showed most strongly near the positive pole. Only for strong currents or for large amounts of metallic vapors in the arc did the region near the positive pole show the spectra of metals at all strongly. In a paper which appeared in a recent number of this *Journal*,[2] Humphreys notes the difference between anode and kathode spectra.

During the past year a research on the spark-discharge in a magnetic field has been carried on in this laboratory. Some observations made during the course of this work suggested a further study of the arc. The method was the same as the one previously employed and the photographs and visual observations in general confirm the earlier results, viz.: that for currents of only a few amperes, the arc between commercial carbons in air shows the spectra of the metallic constituents almost entirely in the region near the negative pole, where the discharge takes the form of a diverging stream; while the region near the positive pole, showing only a trace of these metallic spectra, gives the banded spectra very strongly. The bands may extend quite to the negative pole. A hissing arc or one that is unsteady usually shows the metallic spectra at both poles.

The form of the discharge, particularly of that part from the negative pole, is affected by the position of the arc. If the poles

[1] *Astrophysical Journal*, **16**, 27, 1902.

[2] *Ibid.*, **27**, 194, 1908.

are vertical and the negative one is below, the longer parts of the negative discharge, forming the outer sheath of the arc, appear to reach the positive pole and to envelope it. The dispersed image of this part of the arc shows that sodium vapor forms the outside layer of the discharge, its image being much longer and wider than those due to the other metals. But in general the various images resemble one another in outline. They start at the negative pole as intensely bright and fairly sharp lines, but become broad and hazy toward the positive pole. The corresponding image near the positive pole is little more than a bright point, unless the current is large and much metallic vapor is present. A small piece of any metal introduced into the negative pole gives longer and stronger images in terms of the light from that metal. These images may of course extend nearly or quite to the corresponding ones from the positive terminal.

If the poles are vertical and the negative one is placed above, the discharge from this pole seems to descend and then to be curled outward and back upon itself by the upward rush of the heated air. This is especially well shown by the sodium, though all the images of the negative discharge are shorter than when the negative pole is below, and show flattening and widening at a short distance from their origin.

This convection effect from the heated air is very marked if the carbons are placed horizontal. If sufficient metallic vapor is present, the stream-like discharges proceed from both poles and are curled upward into a common vertical path. The horizontal parts of the streams from the negative pole are longer than those from the other terminal. This difference in length is probably due in part to convection from the unequally heated poles. It is possible, also, that the negative and positive discharges have different velocities.

If the poles are vertical and the positive one is below, the negative discharge disappears very quickly when the arc is broken. But if the negative pole is the lower one, the negative discharge appears to retreat slowly into this lower pole. A similar motion of the blue-green core may be observed at the positive terminal when it is the lower one. Whether there is actual motion, or merely a dying down of incandescence at a distance from the heated terminal, is difficult

to determine. These general results of air convection have an obvious bearing on the question as to what length of arc can be obtained with a given current, as well as upon the resistance of an arc of given length.

If an aluminium plate is put between the poles, and the arc is made, that part of the double arc for which the aluminium is the positive terminal shows the banded spectrum of the oxide very strongly. This banded spectrum is hardly visible when the aluminium is the negative pole. With aluminium as the negative pole, the discharge is explosive and difficult to maintain, but with this metal as the positive terminal, the arc may be made much longer.

I have examined with the revolving mirror the arc from many combinations of metallic poles, but have not been successful in detecting any discharge which was strictly oscillatory.[1] It is frequently explosive, however, giving quite regular interruptions in the discharge, particularly when the negative pole is a metal.

The markings on a metal plate moved between the poles and serving one side as a positive terminal and the other as negative, are strikingly different. An effect analogous to Nobili's rings is easily obtained. The tracings on an aluminium plate which has served as a positive pole have their edges oxidized.

The trace on iron, examined under a microscope, is strongly corroborative of Trotter's[2] observation that parts of the arc may at times be in rapid rotation.

If a zinc rod is held to the positive pole and the arc is made, the rod gives a discharge which may shoot straight out from the rod in a direction apparently quite independent of the position of the negative pole. This rod used as the negative pole gives a violently explosive discharge. The other metals tried gave similar results. The positive and negative discharges from a given metal are quite different in appearance. Each is deflected by a weak magnetic field, the direction being that which would be shown by a stream of charged particles.

The musical arc[3] was also used in this study of the discharge.

[1] Upson, *Philosophical Magazine*, (6), **14**, 126, 1907.

[2] *Proceedings of the Royal Society*, **56**, 262, 1894.

[3] Austin, *Bulletin of Bureau of Standards*, **3**, 325, No. 2, 1907.

As is well known, this form of discharge is produced by connecting in parallel with the arc a system having considerable self-induction and capacity. Oscillations are set up which have approximately a period $2\pi\sqrt{LC}$ and these, acting upon the arc, produce a musical note. Clear tones of nearly constant pitch may be obtained by using vertical poles, the positive one being below. A small carbon is better for the positive terminal, since it soon becomes pointed and thus the arc cannot by wandering change its length and therefore change the pitch of the note emitted.

The result of studying such an arc with a revolving mirror shows that for the arc between carbons in air, the presence of the blue-green core at the positive pole is a necessary condition for a sustained note. I have not been able to produce this musical discharge for more than a moment between metallic poles; nor at all between carbon poles at atmospheric pressure when much metallic vapor was present. But the moment the core of the arc appears at the positive terminal, the oscillations may begin.

The revolving mirror shows that the oscillations of this core are very marked. The negative discharges from metals mixed with the carbons do not show any oscillations until the core begins to move. When the oscillations are once set up, however, the spectrum of the entire arc obtained from a grating revolving rapidly, shows interruptions in the bands from the region near the positive pole and also in the discharges from the negative pole. These interruptions seem to extend throughout the spectrum and, as would be expected, have the same period.

The discharge as a whole does not appear oscillatory, since the core does not appear first at one pole and then at the other. It seems to move out from the positive pole and then back toward that pole. Nor have I been able to detect the metallic discharge except at what would be the negative pole of the arc for steady current.

This form of arc may therefore be considered as an interrupted discharge rather than one which is strictly oscillatory; as if it were the result of superposing an oscillatory discharge upon the steady arc discharge, the impressed effect not being sufficiently intense to cause the poles, although intensely heated, to emit particles to such

an extent as to render the results of the impressed oscillations easily noticeable in the spectroscopic examination of the arc as a whole.

A second carbon joined in parallel with the positive one forms an arc with the negative terminal when it is brought into the outer sheath or flame of the arc. But if this auxiliary terminal is joined in parallel with the negative pole, it arcs with the positive only when it has pierced the outer flame and reached the core. Therefore for the existence of a carbon arc in air it is necessary that at least a part of the negative stream should reach the core which is at the positive terminal.

It is well known that a comparatively weak magnetic field breaks the arc, the discharge as a whole being deflected as a wire would be if it carried the current.

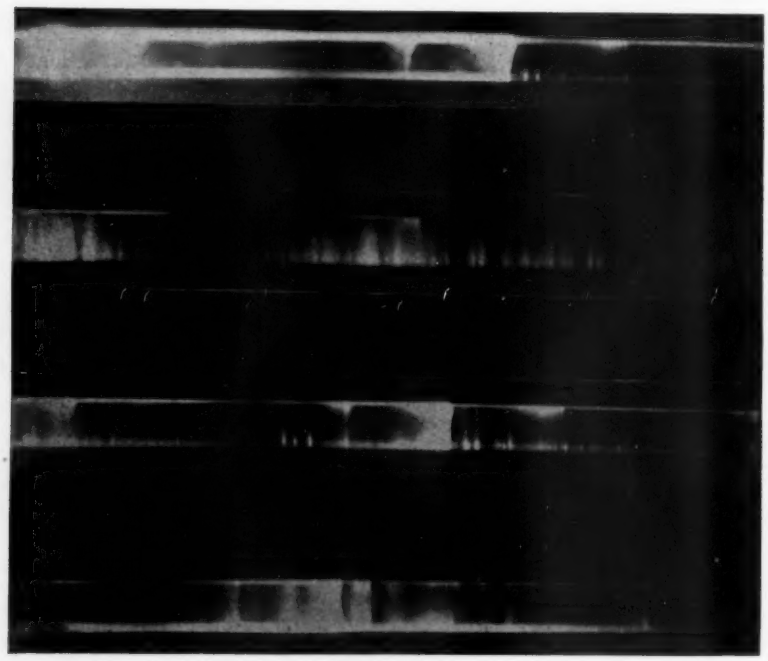
A bar magnet was set swinging near the arc and rough measurements were taken of the resulting deflections of the various images formed by the grating.

If the arc-terminals are of small diameter and the current only a few amperes, these images are fairly well defined. Every part of the arc appeared to be deflected, and to about the same extent. The fact that the various images of the negative discharges differed from one another in length as well as in outline at the broad extremity of the visible discharge rendered accurate measurements difficult.

More careful observations were made on the arc in the nearly uniform field obtained from two coils carrying a current. The discharges from small amounts of zinc and sodium deposited over the surface of the negative pole were of about the same length, although the sodium image appeared to have its origin in the outer layer of the discharge, as if the sodium vapor surrounded that of the zinc. With iron as the negative pole, the images were narrower and sharper.

The results of observations on the separate images produced by the grating indicate that the magnetic field deflects all parts of the negative discharge to the same extent. The series of spectral images of the negative discharge from all of the elements which were introduced into the arc at the negative pole showed deflections in the magnetic field.

Using a short arc, it is easy to obtain upon the negative pole a deposite of carbon from the positive terminal. This deposit takes the "mushroom" form noticed by many observers. It is evident, therefore, that a stream of particles may be given off by the positive pole. That these particles are charged seems to be shown by the effect of a magnetic field upon the discharge giving the deposit.



PLATES TAKEN WITH ENTIRE ARC AS SOURCE

1.—Carbon poles, the upper positive. Current 6 amperes.
2.—Upper pole carbon, positive; lower pole carbon. Current 10 amperes.
3.—Poles carbon on which copper has been deposited; the upper one is positive. Current 6 amperes.
4.—Same as No. 3, except that negative pole is above.

The general results of these observations may be stated as follows:

For weak currents, the discharges at the two poles of a given arc are essentially different in character.

For heavy currents and large amounts of metallic vapor in the arc, the structure of the discharge is less well defined.

The discharge from the negative pole arises from a small, intensely heated region and spreads out toward the positive terminal. Its

appearance and its behavior in a magnetic field suggest that it is a stream of charged particles arising from an incandescent solid.

An examination of the images obtained by using the grating upon the entire arc as a source shows that all images of the luminous discharge are deflected by a magnetic field.

From these results it may be inferred that the arc is maintained by the convection of charges which are associated with particles having their origin at the poles. The nature and size of these particles, as well as their velocity, would of course depend in part upon the gas in which the discharge takes place, and upon the pressure. Their velocity is extremely low compared with that of the particles associated with the discharge in a vacuum tube. Indeed it is probably lower than the velocity of the slowest particles which emit or cause the emission of light in the spark-discharge at ordinary pressures.

The negative arc-discharge seems to be similar to that which is known to be emitted by incandescent bodies. It may fairly be considered analogous to the kathode discharge in a vacuum tube. In appearance this negative part of the arc-discharge is quite similar to that from the negative terminal of a non-oscillatory spark. It is also strongly suggestive of those parts of the oscillatory spark which are negatively charged, easily deflected by a magnetic field, and which give spectra characteristic of the spark terminals.

Further experiments with the arc in a magnetic field are in progress. Quantitative results would have a direct bearing upon the question as to whether, in the various parts of the arc, the particles carry charges which are simple multiples of a common unit.

PHYSICAL LABORATORY
BRYN MAWR COLLEGE
April 1908

THE RELATIVE INTENSITIES OF SPECTRUM LINES

By P. G. NUTTING

Recent advances in spectroscopy have added greatly to our store of data bearing on variations in the relative intensity of spectrum lines produced by varying current, capacity, inductance, temperature, pressure, and other like conditions of excitation. That this accumulation of facts is capable of reduction to but a very few variables is believed by most spectroscopists, but no one appears to have attempted the task. In this paper I shall attempt to show that a single variable, or at most two, is sufficient.

Every spectrum line of every element appears to require a certain well-defined minimum of some energizing influence for its production. This is quite different from the thermal emission of solids, which is supposed to continue down to the absolute zero of temperature. If this minimum of exciting influence is exceeded, the spectrum line increases continually in intensity with increasing excitation. If this minimum is expressible without hypothesis, in terms of a known measurable quantity, we have an ideal basis of classification of lines.

For the sake of brevity, let us speak of "hard" and "soft" lines, the "harder" the line the greater the initial excitation necessary and the greedier of energy when the supply is generous. In most spectra lines may be grouped according to hardness, frequently into but two general groups, the primary and secondary spectra, differing widely in conditions of excitation but always overlapping to some extent; that is, the soft or primary spectrum does not disappear as soon as the hard or secondary spectrum appears. This overlapping is least with the acid-forming elements.

Graphically, if we plot energy of line against total energy, the curves (which are very nearly straight lines) for soft lines will intercept the axis of total energy near the origin, while the harder lines are characterized by a larger intercept and in general by a larger angle of interception as well. In the case of a radiating black or gray body all such curves pass through the origin tangent to the total energy axis.

Several years ago the writer[1] gave the steepness of the wave-front through a gas as condition for the preponderance of the secondary over the primary spectrum. Crew[2] almost at the same time concluded that "a high E. M. F., rapidly changing, is a probable *conditio sine qua non* for the appearance of spark lines in arc spectra." Both might better have expressed their results in terms of potential gradient.

Let us consider arc, spark, and vacuum-tube spectra from the single standpoint of potential-gradient in the luminous gas. The lowest gradients are obtained in heavy current arcs and Plücker tubes with wide capillary; in the former case the low gradient is due to the heavy current, in the latter to low gas-pressure. Higher potential gradients are obtained in arcs with very small current, Plücker tubes with fine capillaries and sparks with small capacity and large inductance. The highest potential-gradients are found in sparks and other interrupted arcs, the gradient increasing with the amount of capacity in circuit and with the impressed voltage. Gradients vary from about 20 to 80 volts per cm in ordinary arcs and tubes up to thousands of volts per cm in condensed sparks.

Consider the simple case of hydrogen in a Plücker tube. To obtain the white glow, giving the primary spectrum, we use a capillary of several mm diameter, gas at the pressure of its maximum conductivity, and a moderate steady current—just the conditions for low potential-gradient. To get the red secondary it is sufficient merely to use a very fine capillary, thereby raising the potential-gradient from about ten up to several hundred volts per cm. Increasing the density of the hydrogen helps because it increases the gradient. The short cut from primary to secondary lines is of course to use a series spark with capacity, provided the gas density is sufficient (1 cm or over) to support a high gradient. Inductance reduces the gradient down to a minimum, beyond which it is inoperative.

In the arc, potential-gradients may be similarly varied but under more complex conditions. Varying the length of an arc does not greatly affect either the potential gradient within it nor its spectrum, nor does varying the pressure of the surrounding atmosphere over a wide range from one-tenth to ten atmospheres. As to the relation of

[1] *Astrophysical Journal*, **20**, 135, 1904.

[2] *Ibid.*, **20**, 284, 1904.

potential-gradient to current, external resistance, and impressed voltage, we must consult a Kaufmann diagram. This shows that potential-gradient is practically a function of current alone, but in a manner entirely different from that indicated by Ohm's law. For currents of from one or two amperes up, it is low and nearly independent of the current, but below one ampere it increases very rapidly with decrease of current, reaching thousands of volts at a few hundredths of an ampere. A mercury arc or Nernst filament will operate very well on a 5000-volt circuit at but slightly decreased efficiency but with a very slight current and enormously increased gradient.

A discussion of the Kaufmann diagram as applied to arc, spark, and vacuum tube has been given by the author[1] together with the results of work on the spectra of arcs at 4000 volts and 0.05 ampere. The appearance of "hard" or spark lines in low current arc spectra had previously been noted by many observers, but they are especially striking in the writer's spectrograms taken under the extreme conditions mentioned. In some cases, these lines appear only within about $\frac{1}{2}$ mm of the electrodes of the 2 mm arc, as though not much of the electrode metal was vaporized, while with antimony, bismuth, and cadmium, the spark lines extend quite across the arc.

In the condensed spark without inductance, the front of the pilot discharge must have a potential-gradient not much below the dielectric strength of the intervening gas. The remainder of the discharge is probably at a very low gradient, approaching that of a direct-current arc. Hence such a spark gives both spark and arc lines. Inductance and resistance lower maximum gradients by smoothing out the current wave. The spectrum of a spark rendered dead beat by series resistance can scarcely be distinguished from that of a low direct-current arc.

TEMPERATURE AND PRESSURE

We have considered the intensity of a spectrum line as expressible in terms of but two constants and one independent variable. These two constants are the intersection and slope of the curve relating line energy to total energy. The independent variable is the specific

[1] *Bulletin of Bureau of Standards*, 1, 399–416, 1905.

energy content of the luminous gas, but, since that quantity is difficult of determination, we have spoken instead of potential-gradient, its chief component in cases of electrical excitation and a quantity very nearly proportional to it. Let us consider briefly the effects of temperature and pressure as parameters.

We have every reason to suppose that an electric current sufficient to bring a gas to the neighborhood of its maximum conductivity brings all the particles of the gas into action. The "saturation" of the current indicates complete ionization on the one hand, and on the other the ratio of line width to line intensity[1] indicates that an increase in the current does not bring into play more particles of the same kind but only excites more intensely those already radiating. The completeness of the excitation is remarkably independent of the kinetic motions of the gas particles, be they fast or slow.

But on merely heating a gas to a high temperature, only a few of the faster-moving particles are at first raised above the critical condition of radiation. If, however, a gas could be maintained at so high a temperature that, say 95 per cent. of the particles were above their critical condition, then thermal excitation would produce radiation comparable with electrical excitation. J. J. Thomson's simile of burning the kitchen to boil the pot seems hardly fair, at least it is not the inefficiency of the gas as a radiator, but the difficulty of getting energy to it rapidly enough, that makes thermal excitation inferior to electrical.

But temperature and pressure together may produce large local supplies of energy within a gas by thermo-chemical processes under such conditions as are supposed to exist in the sun and hotter stars. Consider a large mass of a mixture of two gases which combine freely at one temperature and pressure and which dissociate at some other temperature and pressure. Then a long-continued slow change with absorption of heat, followed by a slight gravitational displacement, might cause an enormous local liberation of energy continuing over a longer period of time as the mass departed from homogeneity.

If stellar luminosity is due chiefly to such causes, then luminosity should depend upon the mass as well as upon the temperature of the star, for it would be greatest with enormous pressure- and density-

[1] *Astrophysical Journal*, **24**, 116, 1906.

gradients. The point to be emphasized here is that for thermochemical as well as other forms of excitation, spectroscopic evidence is in favor of relating the intensity of each spectrum line to a single variable and two constants.

In conclusion, I wish to enter a plea for a simpler and broader basis for spectroscopy and a basis as free as possible from either assumption or speculation. Some such general variable as that here suggested is required to sweep away the mystery surrounding arc, spark, and tube spectra, and rescue spectroscopy from a seemingly hopeless fortuity.

BUREAU OF STANDARDS
WASHINGTON, D. C.
May 1908

NOTE ON SERIES IN ALKALI METAL SPECTRA

By F. A. SAUNDERS

In a dissertation of unusual interest, A. Bergmann has recently announced, among other new series, one in the spectrum of caesium, which Runge[1] thinks is related to the first subordinate series of that element. Ritz[2] has very lately noted the fact that this series is not entirely new and that there are very serious objections to Runge's proposition. I should be glad to be allowed to add a few comments.

At the time when my work on these spectra was published[3] I endeavored to bring every line in the arc spectrum of caesium into the series classification. There was an odd one at λ 9171 for which I imagined an (undiscovered) mate, thus making up a pair. There were six other pairs in an obvious series arrangement, which I was obliged to split into two series to accommodate this questionable pair. On coming back to the matter again, I saw (it should have been apparent before) that λ 9171 is needed elsewhere, and that the six pairs, with another, discovered by Bergmann, rightly belong, as he has classified them, in one series, whose approximate equation he has given. Since he was not acquainted with my measurements, I think it worth while to tabulate, below, the complete series, as far as now known, and recalculate the formula, using the best values for the wave-lengths.

I have already pointed out that the pairs of all first subordinate series are really triple. As examples I might mention the groups *Cs:* λ 6983.8, 6973.1, 6723.7; *Rb:* λ 7759.5, 7757.9, 7619.2; *Ca:* λ 3181.40, 3179.45, 3158.98. The first of these lines is always relatively faint, but is the more important theoretically, since the constancy of wave-number difference holds between it and the short wave-length line of the three, and not between the two strong lines, as was first supposed. Now, the line λ 9171 of caesium belongs to just such a "pair" (9211, 9171, 8766) of the first subordinate

[1] *Astrophysical Journal*, **27**, 158, 1908, and *Physikalische Zeitschrift*, **9**, 1, 1908.

[2] *Physikalische Zeitschrift*, **9**, 244, 1908.

[3] *Astrophysical Journal*, **20**, 188, 1904.

series, and thus all the lines of the arc spectrum fall into the series classification.

The columns of the table show (1) the observed wave-length, (2) the stated error, (3) the value of the integer m in the series formula, (4) the initial of the observer (B = Bergmann, L = Lehmann, S = the writer), (5) the wave-length calculated from the formula given below, (6) the difference between the observed and calculated wave-lengths, and (7) the wave-number differences for the pairs. Calculated values are given for the possible first term of the series for which $m=2$. This has not yet been certainly observed, and Ritz points out that it may not exist after all. The formula is calculated using wave-lengths reduced to vacuum, and runs as follows:

$$\frac{1}{\lambda} = \left\{ \begin{matrix} 16899.6 \\ 16802.0 \end{matrix} \right\} - \frac{109675}{(m+0.9762)^2}.$$

THIRD SUBORDINATE SERIES OF CAESIUM

Wave-Length	Error	m	Observer	Calculated Wave-Length	Calc.—Obs.	Wave-Number Difference
		2		22620.		97.6
		2		22437.		
10127.	?	3	B	10134.	+7.	97.4
10028.	?	3	B	10034.	+6.	
8082.0	0.5	4	L	8080.0	−2.0	96.2
8019.6	0.5	4	L	8016.7	−2.9	
7280.5	1.	5	S	7280.5	0	98.5
7228.8	1.	5	S	7229.0	+0.2	
6872.6	1.	6	S	6871.7	−0.9	97.4
6826.9	1.	6	S	6825.9	−1.0	
6630.5	1.	7	S	6630.3	−0.2	97.3
6588.0	1.	7	S	6587.7	−0.3	
6475.	2.	8	S	6475.	0	99.
6434.	2.	8	S	6434.	0	
6359.	5.	9	S	6368.	+9.	84.
6325.	5.	9	S	6329.	+4.	

It is to be noticed that the formula is very simple, since it contains only two adjustable constants (109675 is the universal constant used by Ritz) and yet the observations are sufficiently well represented. It is likely that another constant would have to be added to make the formula include the pair near 2 μ, if that were known.

It may be thought that the line λ 6588 comes too near the relatively strong *Cs* line 6587.3 of the second subordinate series to be really measurable. The line 6588 is 40 Å. broad on some of my negatives,

and lies like a cloud "behind" the sharp series line. Comparison with the other series lines, such as 6355.3, which have no such halo, shows that my interpretation is necessary, but the measurement is, of course, very uncertain.

Runge believes that this series may be found to be a second sort of principal series, closely related to the first subordinate series. Ritz has already objected on the ground that the wave-number differences are constant. I should like to add that the stronger line of each pair has the greater wave-length; this is characteristic of all subordinate series and is just opposite to the principal series arrangement.

The third subordinate series, found by Lenard in the sodium spectrum, seems to be very similar to this one in the caesium spectrum. It presents a similar hazy aspect, is equally faint, and has a wave-number difference which does not agree with that of the usual series; but it seems to run to the same end as these, wherein it differs from the new caesium series. Bergmann finds a new line at λ 12680 in the sodium spectrum. This is probably an unresolved pair belonging to Lenard's series. If we consider it so, it can be included with the others by a formula similar to that of Ritz, with one small modification. The table shows how well this can be done; it is to be noted that the lines are not very accurately measured.

THIRD SUBORDINATE SERIES OF SODIUM

Observed Wave-Length	Error	Calculated Wave-Length	Calc.—Obs.	Wave-Number Differences
12680.	?	12680.	0	Not resolved
7377.4	0.4	7377.5	+0.1	14.72
7369.4	0.4	7369.4	0	
5532.7	0.4	5533.0	+0.3	14.77
5528.2	0.4	5528.5	+0.3	
4918.4	1.	4917.3	−1.1	18.
4914.0	1.	4915.5	+1.5	
4629.5	1.	4630.2	+0.7	18.
4625.5	1.	4626.3	+0.8	
4472.5	2.	4470.8	−1.7	Not resolved
4372.	5.	4372.5	+0.5	Not resolved

The formula runs:

$$\frac{1}{\lambda} = \left\{ \begin{matrix} 24549.8 \\ 24535.0 \end{matrix} \right\} - \frac{109675}{\left\{ m - 0.5772 + \dfrac{0.6778}{1 - \dfrac{6.517}{m^4}} \right\}^2}$$

It contains four adjustable constants, and is not to be recommended for its simplicity. I have already expressed my conviction that almost any sort of a four-constant formula can be used to represent a series which is inaccurately measured. Unfortunately all four constants seem to be required in many cases, especially when the series is completely known. A universally applicable three-constant formula is still to be found, notwithstanding the brilliant work of Ritz, and others. This particular sodium series is not a good one to use to help decide on the best type of formula, as it is so hazy and faint, but there are several others that are available. Long and intimate acquaintance with some of these, especially Rydberg's series of single lines in magnesium, has brought me to the opinion that none of the existing formulae will quite perfectly represent them. Hence I am at present driven to make use of such a one as above.

SYRACUSE UNIVERSITY
May 1908

POLARIZED FLUORESCENCE OF METALLIC VAPORS AND THE SOLAR CORONA

By R. W. WOOD

The presence of radially polarized light in the solar corona has always been regarded as almost proof positive that a part at least of the light is sunlight, scattered by very small particles. If this is the case we should expect to find the Fraunhofer lines in the spectrum Now the majority of the observations which have been made of the spectrum of the corona show that these lines are absent, though in a few cases very slight evidences of them have been seen. A very slight trace of them could undoubtedly be explained by superposed sky-light. To account for the absence of these lines it has seemed necessary to explain the emission of the corona as due, in part, to incandescent liquid or solid particles. This view is, however, difficult to reconcile with Abbot's bolometric observation of a cold corona. As I pointed out in an article on the nature of the corona published in this *Journal* in January 1901 (**13**, 68), the absence of the longer waves could be explained by the smallness of the scattering particles, for it was found that the minute carbon particles in a candle flame scattered blue and violet light powerfully, green to a much less degree, and red not at all. There remains, however, the matter of the continuous spectrum, for light emitted in virtue of incandescence should show marked heating effects. Upon the whole it appears to me that no theory of the corona, advanced up to the present time, explains the phenomenon in a satisfactory manner.

I have recently found, however, that the fluorescent light emitted by comparatively cool metallic vapors, when a powerful beam of light is passed though them, is very strongly polarized, and that moreover the percentage of polarized light is almost exactly what we should expect in the corona, if that phenomenon were due to the fluorescence of a great cloud of mixed metallic vapors surrounding the sun, under the influence of the very intense illumination to which it is subjected.

Thus far I have detected the presence of polarized light in the fluorescence of sodium, potassium, and iodine vapor.

A Savart polariscope was used, and the percentage of polarization measured by compensating it with one or more glass plates, which could be rotated on a vertical axis, furnished with a graduated circle.

The apparatus used in the experiments is shown in Fig. 1, a description of which was published in this *Journal* in September 1903 (**18**, 96). If the incident light was plane polarized to start with (the vibrations or electric vector being in a vertical plane), 30 per cent. of the fluorescent light was found to be plane polarized. If the exciting beam was unpolarized the percentage dropped to fifteen.

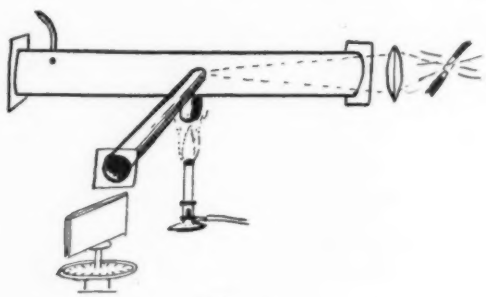


FIG. 1

The fluorescent cone of light was observed through the lateral tube at an angle of 90° with the exciting beam. The results in detail, together with the precautions taken to eliminate all possible sources of error, such as the presence of fog in the tube, will be found in the current number of the *Philosophical Magazine*. The fact that the percentage of polarized light, when the exciting light was unpolarized, is almost exactly equal to that shown by the corona, is most suggestive. The corona, it is true, shows only about 11 per cent., but it must be remembered that the angular convergence of the rays from the sun at a distance of one solar diameter is much greater than that obtained from the double convex lens which furnished the exciting beam in the laboratory experiment. This would make the percentage of polarization slightly less in the case of the corona (coronal polarization, 11 per cent.; laboratory experiment, 15 per cent.).

The fluorescence spectrum of a mixture of metallic vapors would

undoubtedly appear continuous, or practically so, with all dispersions that have ever been brought to bear upon the corona. The fluorescence spectrum of sodium vapor alone is made up of thousands of very fine lines arranged in groups or bands. The bands can be seen with instruments of low dispersive power. The color of the fluorescent light is a very pure and brilliant green. (See paper in the *Philosophical Magazine* for May, "The Resonance Spectra of Sodium Vapor.") A mixture of potassium and sodium vapors gives a brilliant white fluorescence tinged with yellow.

It is clear that with a suitable mixture of vapors we could have a fluorescence tinged with almost any color we pleased according to the proportion of the vapors constituting the mixture. The majority of observers seem to be of the opinion that the solar corona emits a light which is far from being white. The color may be in part due to the so-called green coronium line, but fluorescence would explain it at once, as well as the absence of radiant heat, for it is doubtful if the fluorescence spectrum extends very far beyond the visible red. An observation of Sir Norman Lockyer is of interest in connection with a fluorescence theory of the corona.

In his *Chemistry of the Sun*, p. 365, he writes as follows regarding his observation of the spectrum of the corona at the eclipse of 1882: "The spectrum of the corona, as I saw it in Egypt, was of the most complex nature. It was distinctly not a continuous spectrum such as[1] that given by the lime light. Instead of the gradual smooth toning seen, say, in the spectrum of the lime light, there were maxima and minima, producing an appearance of ribbed structure, the lines of hydrogen and 1474 being of course over all. Of other bright lines distinct at any great distance from the photosphere I saw none, nor any very marked absorption lines, not even D or *b*. *But what I really did see was as if all the banded spectra I had ever seen were superposed.* My instrument was a short focus photographic objective of six inches aperture and one flint prism, so that the light in the spectrum was ample. One could be certain of what one saw."

Inasmuch as band spectra appear to be characteristic of fluorescing metallic vapors, this observation is certainly very suggestive. A

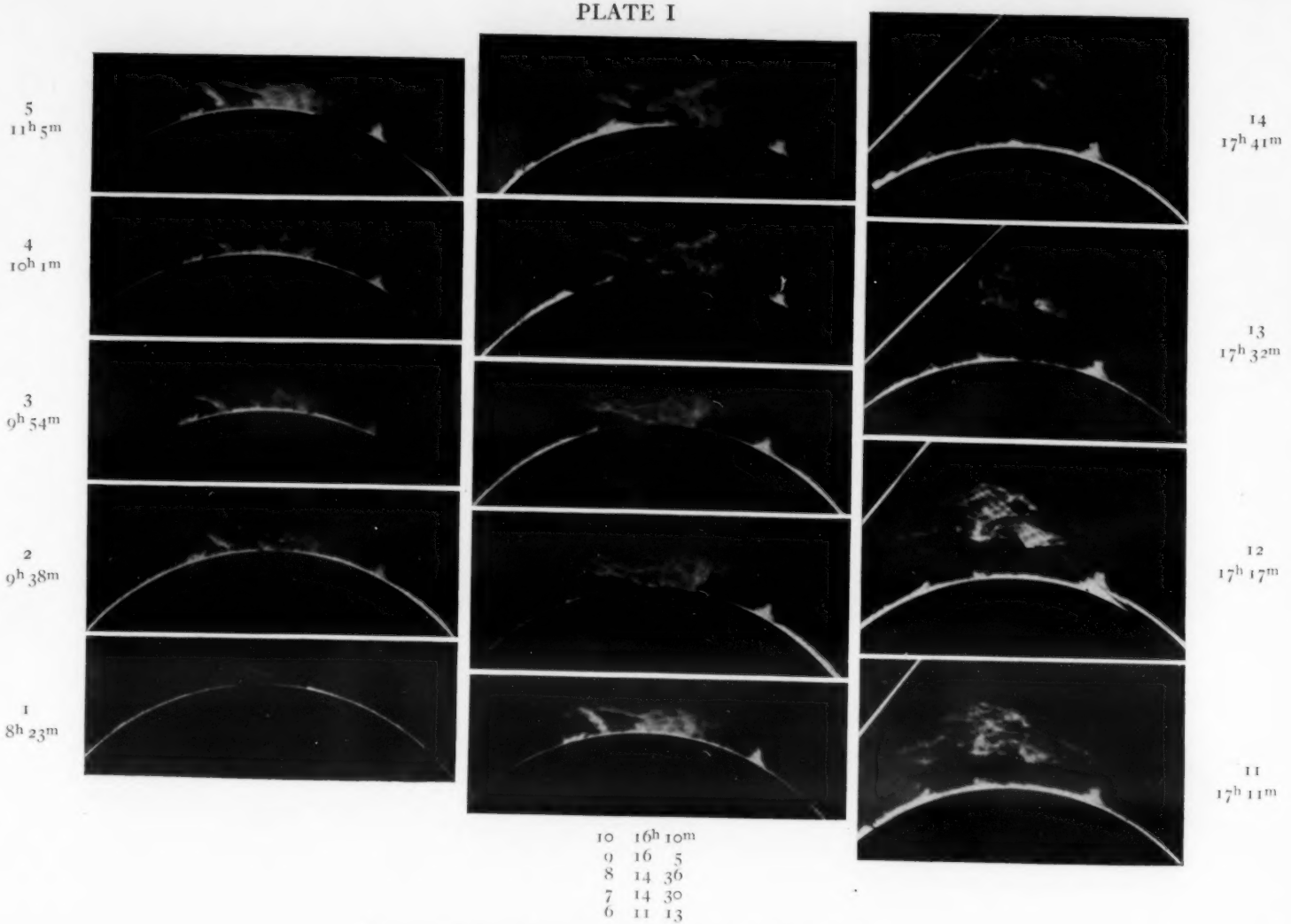
[1] Lockyer used the word "resembling," which makes his meaning a little ambiguous.

spectroscope of low dispersion will often give unmistakable evidence of faint bands, when an instrument of higher power fails to reveal any trace of them. This I have frequently noticed in studying the spectra of fluorescent vapors.

It appears to me to be quite possible that the green coronium line, as well as the other bright lines, which have been observed in the corona's spectrum and which have not been identified with any known terrestrial substance, may be the fluorescent lines of some well-known substance or substances. As I have shown, the fluorescent lines of sodium vapor do not coincide with any emission lines obtained in any other way. It is even possible that the Fraunhofer lines may have their origin in coronal absorption. This, however, is a question which can be better discussed by those who are engaged with the study of solar physics. It seems certain, however, that we are no longer forced to attribute coronal polarization to the scattering of light by small particles. The fluorescence of a metallic vapor is quite a different phenomenon, as there is a change of wave-length.

JOHNS HOPKINS UNIVERSITY
May 15, 1908

PLATE I



PROMINENCE OF FEBRUARY 18, 1908 (Indian Standard Time)

A LARGE PROMINENCE

By J. EVERSHED

By a fortunate chance the writer was able to secure a good series of plates, showing the development and final rapid ascent of a very large prominence. This was of a type that has seldom been recorded previously.

At this observatory it is part of the usual routine with the spectro-heliograph to secure daily two good plates of the prominences. These are obtained ordinarily between the hours of eight and nine in the morning, when definition is at its best. On February 18, 1908, the second plate exposed turned out to be rather a poor one, but the first, exposed at $8^h\ 23^m$, was good. The prominences were, however, small, and there seemed to be nothing of special interest on the limb. Fortunately, it was thought worth while to expose a third plate. This was done at $9^h\ 38^m$, and the result showed that there had occurred a remarkable development of a prominence shown faintly in the first two plates, extending from the position-angle 89° to 127°.

Realizing the unusual nature of the newly developed group of prominences, arrangements were made to continue photographing this part of the limb throughout the day, which was fortunately perfectly clear from sunrise to sunset. It should be stated that visual observations in the *Hα* line, were made between $8^h\ 40^m$ and $10^h\ 30^m$, and this region of the limb was sketched by Mr. Sitarama Aiyar between $8^h\ 43^m$ and $9^h\ 3^m$. His drawings show a moderately bright mass of prominences, extending from position-angle 89° to 121°, having bright condensations at 91° and 97°. The sodium and magnesium lines were noted as bright at 91°. The main mass was estimated at 50″ in height at $8^h\ 50^m$, and 85″ an hour later. A smaller but bright prominence was situated at P. A. 135°, and this also increased during the observation from 45″ to 80″.

Twenty photographs in all were secured during the day, two exposures being made on each plate after the first three, and fourteen of these are shown in the accompanying reproductions (Plate I). The

definition became very poor between 12^h and 17^h and good guiding was then impossible, the image moving bodily on the slit plate. This is shown in the irregularities of the limb seen in Nos. 7 to 10. Later, the definition improved, but the last plate, exposed at $18^h\ 2^m$, was much underexposed, owing to thick smoke from forest fires passing over the sun's disc. The image No. 12 is somewhat distorted through the electric guiding control failing to act; and the disk excluding the photosphere had to be moved, to prevent fogging the plate. The position-angle of the small bright prominence seen in all the photographs except No. 1 was 135°, equal to solar latitude −63°, and from this position the prominence extends to P. A. 89°, equal to solar latitude −17°.

Notwithstanding the very sudden appearance of such an enormously extended mass between the hours of 8 and 9, the subsequent increase in size took place quite slowly. Visual observations in the *Hα* line showed scarcely any evidence of motion in the line of sight, such as usually accompanies great eruptions. The actual increase in height determined from measurements at a definite point on the limb (P. A. 116″) is shown in the following table, which also gives the approximate rate of ascent in the mean interval between successive pairs of photographs. The most striking feature is the accelerating velocity with which the entire mass leaves the sun. A reference to the last four photographs of the series here given will show this clearly. The prominence also appears to diminish in brightness as it ascends, but this is no doubt due in part to the rapidly diminishing altitude of the sun, which at $17^h\ 41^m$ was only 8°, and at $18^h\ 2^m$ was less than 3° above the horizon; the two images in the last plate were too faint for reproduction.

Another feature of interest is the long filament joined to the main mass and arching over the small bright prominence. In the negatives it appears to be connected with the top of the small prominence at $11^h\ 5^m$ but becomes disconnected at $14^h\ 36^m$; at $17^h\ 11^m$ it is joined to the chromosphere beyond, at P. A. 139°. The movement of the whole mass, from this time on, is greatest at the parts most remote from the filament, and gives one the impression that the latter acted like a flexible cord, holding one end of the mass to the sun and forcing it to swing out in a curve.

HEIGHTS OF PROMINENCE MEASURED AT POSITION-ANGLE 116°

Number of Plate	Indian Standard Time*	Mean Height in Seconds of Arc	Approximate Velocity of Ascent
	h. m.		km per sec.
271.....	8 23	...	
274.....	9 38	81	
			12
275.....	9 54	100	
	10 1		
			1.2
276.....	11 5	107	
	11 13		
			2.5
279.....	14 30	150	
	14 36		6.7
280.....	16 5	202	
	16 10		
			24
281.....	17 11	337	
	17 17		
			37
282.....	17 32	405	
	17 41		
			84
283.....	17 56	Too faint to measure	
	18 2	585	

* $5^h\ 30^m$ in advance of Greenwich mean time.

The writer has met with only two previous examples of prominences having the same characteristics as the one of February 18 last, and in neither instance was it possible to follow out the changes at all completely. The first was observed in its earlier stages at the writer's private observatory at Kenley, on the date October 3, 1892. Between 7^h and 9^h G.M.T. it was a large mass of complex filaments, extending from latitude $-21°$ to $-39°$ on the S.E. limb, with small bright prominences at $-15°$ and $-42°$. At 2:00 P.M. Kalocsa M. T., it was observed by Herr Fényi, and at this time had attained the height of 8′ 51″. His measurements indicated a rapid rise of the upper part, which showed a mean velocity exceeding 36 km per second. At $2^h\ 55^m$ nothing remained of the higher part. Displacements of the spectral lines did not occur.[1]

The other prominence, apparently of the same type, was photographed here, on April 9, 1907. Like the former, it consisted of a

[1] *Astronomy and Astrophysics*, **12**, 38, 1893.

huge mass of interlaced filaments. It extended from solar latitude +16° to +38° on the east limb. Only three photographs were obtained, and the heights measured on these are as follows:

No. of Plate	I. S. T.	Height	Approximate Velocity of Ascent
452.....	$8^h\ 34^m$	105″	7 km per sec.
456.....	8 55	117	12 km per sec.
457.....	9 13	135	

An increasing rate of ascent is here indicated. The prominence had disappeared on the following day. It would be interesting to know whether this prominence was observed in its later stages elsewhere.

It is perhaps worthy of remark that the disc photographs in K light, obtained on the dates April 9, 1907, and February 18, 1908, show no flocculi nor any kind of disturbance at or near the positions of the prominences.

SOLAR OBSERVATORY
KODAIKANAL, SOUTH INDIA

Minor Contributions and Notes

REMARKS ON THE USE OF THE SELENIUM CELL IN PHOTOMETRY

Within the past few months Messrs. Stebbins and Brown, of the University of Illinois, have presented several papers[1] on the application of the selenium cell to photometric measurements. Inasmuch as these papers contain statements which are liable to be misleading, I have thought it desirable to make a few remarks upon the subject in general.

In his most recent paper on "The Color-Sensibility of Selenium Cells," Mr. Stebbins gives a number of curves representing the variations of resistance of selenium with the wave-length of the incident light. As a matter of fact, these curves are not true sensibility curves as no account has been taken of the distribution of energy in the spectrum of the source of light (in this case, the sun). Several years ago I had occasion to determine the sensibility curves of a number of selenium cells.[2] As was pointed out at that time, the energy carried by each bundle of approximately homogeneous radiations, before being permitted to fall upon the cell, was made the same in all cases (the energy measurements being carried out by means of a Rubens' thermopile and galvanometer). Such curves, as contrasted with those of Mr. Stebbins, will not vary with the character of the source but will represent only the peculiarities of the cell itself. If the distribution of energy in the spectrum used by Stebbins were known, it might be possible to apply the desired corrections, but, unfortunately, this is impossible at the present time. Although the solar energy curve is known (having been determined by the use of prisms), the fact that Stebbins and Brown employed a grating which is liable to superimpose peculiarities of its own upon the spectrum, makes former energy determinations inapplicable to the present case. It is only after the distribution of energy in the spectrum used shall

[1] *Astrophysical Journal*, **26**, 326, 1907; **27**, 183, 1908.

[2] *Philosophical Magazine*, (6), **7**, 26, 1904.

have been determined that the curves in question may be transformed into true sensibility curves.

In their earlier paper Messrs. Stebbins and Brown compare values of the candle-power of moonlight, determined visually, with those determined by means of the selenium cell, and find that the latter vary among themselves by more than 500 per cent. These differences are satisfactorily accounted for in the later paper, where it is shown that different cells have different sensibility curves. In regard to this work I am of the opinion that no good ground exists for the making of such comparisons of candle-power until it shall have been shown that the sensibility curve of the selenium cell is the same as that of the human eye, and that the integration of the effects of various wave-lengths is the same in both cases. To my knowledge, no work has been done on the latter subject, but as to the former, it is evident that the necessary conditions for comparison are decidedly not fulfilled. In fact, if we were to use a cell which is highly sensitive in the red, and comparatively insensitive in the green and blue, we are liable to make the discovery that a red-hot poker is a better illuminant than a mercury-vapor arc.

With the intention of applying the selenium cell to photometric measurements, some experiments bearing on this subject were begun here—but on account of the illness of the graduate student who collaborated with me, and on account of a lack of time on my part, the work had to be discontinued before it was fairly begun. Nevertheless, we succeeded in convincing ourselves of the feasibility of our undertaking which, briefly, was this: given a cell whose sensibility curve has been accurately determined, to produce a color-screen such that the resultant sensibility curve of selenium cell and color-screen shall be the same as that of the normal human eye for a definite intensity of illumination. Whether or not such an arrangement might be of service in the determination of stellar magnitudes, remains to be seen. The facts in the case are these: there is no difficulty in constructing cells (as I have convinced myself by actual trial) having an effective area varying from less than 1 sq. mm to 20 sq. cm; by the use of extra-focal images, the entire area of the cell may be utilized and by employing a source of high electrical potential together with an Einthoven string-galvanometer[1] (having a sensi-

[1] *Annalen der Physik*, 21, 483, 1906.

bility of 1×10^{-11} amperes) there is at least a possibility of obtaining useful results. A discussion of the Purkinje effect, integration of various wave-lengths, hysteresis, etc., will follow later in connection with a full account of the work.

In my opinion, the only measurements, carried out by means of the selenium cell, which are warranted at the present time, are those involving a determination of the variations of intensity in the same source of light whose effective area alone changes. Some very excellent results of this character have already been obtained, among which might be mentioned those of Messrs. Stebbins and Brown,[1] on the variations of moonlight during a complete period and those of Ruhmer[2] and others[3] on the variations of light during an eclipse of the sun.

A. H. PFUND

JOHNS HOPKINS UNIVERSITY
May 1908

ON THE TRANSPARENCY OF BORIC ANHYDRIDE

Mr. Fritsch[4] and Mr. Zschimmer[5] have both called attention to the transparency of boric anhydride for ultra-violet light. Mr. Fritsch states that, as far as he could observe in a qualitative way with a quartz spectrograph, B_2O_3 exerted no absorption in the region of short wave-lengths.

In view of these facts it seemed worth while to determine the absorption of this substance in the region of light more refrangible than λ 1850. The experiment was carried on with a vacuum grating spectroscope in the manner previously described by the writer.[6] As a result of the observations it appears that boric anhydride in thicknesses of one or two millimeters is not transparent, for practical purposes, to light of shorter wave-length than λ 1700. This substance is, therefore, of the same order of transparency as purple fluorite.[7] It is less transparent than quartz of the same thickness.

THEODORE LYMAN

JEFFERSON PHYSICAL LABORATORY
HARVARD UNIVERSITY
May 1, 1908

[1] *Astrophysical Journal*, **26**, 326, 1907.
[2] *Electrotechnische Ztschr.*, **25**, 1025, 1904.
[3] *Physikalische Ztschr.*, **6**, 838, 1905.
[4] *Ibid.*, **8**, 518, August 1, 1907.
[5] *Ibid.*, **8**, 611, September 15, 1907.
[6] *Astrophysical Journal*, **23**, 196, 1906.
[7] *Ibid.*, **25**, 50, 1907.

INVITATION FOR SUBSCRIPTIONS TO THE PHOTOGRAPHIC CHARTS BY JOHANN PALISA AND MAX WOLF

Professor Max Wolf, of Heidelberg, has much facilitated my task of finding and observing small planets, especially those of the faintest magnitudes, by sending me copies of his photographs; so that now it takes me only about one-fourth the time formerly required to find them. This suggested to me the idea that it would be a great advantage if the photographs of the Heidelberg Astrophysical Institute were made available for every observer in a form suitable for immediate use. As Professor Wolf had intended at a later time to collect his photographs and join them in a map, he kindly offered to furnish positives free of cost. On these positives a reseau is then carefully cut, the curvature of the parallels being determined by the stars themselves. Each plate covers 50 square degrees, the scale being 36 mm to the degree. Contact prints are then made from the positives, on smooth but not glossy bromide paper; and the necessary text, including the numbers for right ascension and declination, is then printed on the sheets, which admit of pencil entries and erasures.

So far a series of twenty plates has been provided with graduations, and the prints will be ready by the last of July. This is a private undertaking, and as the cost of the maps must be borne by those who order them, I invite subscriptions. As the paper is the most expensive item, and I cannot risk pecuniary loss, only as many maps will be printed as are subscribed for in advance. If separate sheets are printed later the cost will be somewhat greater.

I have not attached a scale of magnitudes to these maps for two reasons. On account of different exposures, disks of equal size do not represent the same magnitude on different plates, and even on a single plate the scale is not the same at the center and near the edge. On the average the limiting magnitude on the prints is the same as that of the great refractor of the Vienna Observatory; accordingly the maps extend down to the fourteenth magnitude.

The price of the series is seven dollars and a half for the twenty sheets. After December 31, 1908, when the subscription will close, the price will be ten dollars. I request my honored colleagues and the institutions wishing the maps kindly to order them as soon as

possible, before December 31 at the latest; and in order to save me trouble, to send the money in advance. In acknowledging the receipt of the maps the purchasers will confer a favor by informing me if they intend to order any further series, as two or three additional series, at the most, might be prepared in the course of a year.

As already mentioned, this undertaking is by Professor Wolf and myself. I alone sign this invitation because I have taken in hand the second part of the work, and will have charge of the list of subscriptions and the delivery of the maps. JOHANN PALISA

OBSERVATORY
TÜRKENSCHANTZSTRASSE 17
VIENNA, AUSTRIA

PHOTOGRAPHIC PRINTS OF THE FIELDS COVERED BY THE HAGEN CHARTS AROUND THE FAINTER VARIABLE STARS

Many of the fields around faint variables had been photographed with the 24-inch reflector of the Yerkes Observatory, and at Father Hagen's request the programme was extended to include all of his charts in Series I, II, III, and VI, in which the variable reaches the thirteenth magnitude or fainter at minimum. Out of the 193 fields in the four series, the variable becomes sufficiently faint in 140 cases. These have been photographed, and negative prints on bromide paper, 8 by 10 inches in size, can be supplied to order during the autumn of 1908 or later. A list of the fields photographed will be furnished on request. The scale of the prints will be 10″ to 1 mm; therefore the field covered will be 0.8 of a degree square. For galactic fields, crowded with stars, prints on double this scale can be supplied. The name of the field, the place for 1900, and the orientation will be marked on the print. The variable itself will be inclosed in a small circle; therefore the Hagen chart will serve as an index, the brighter stars can be identified on his lists, and with the known scale the positions of the fainter stars relative to the variable can be determined.

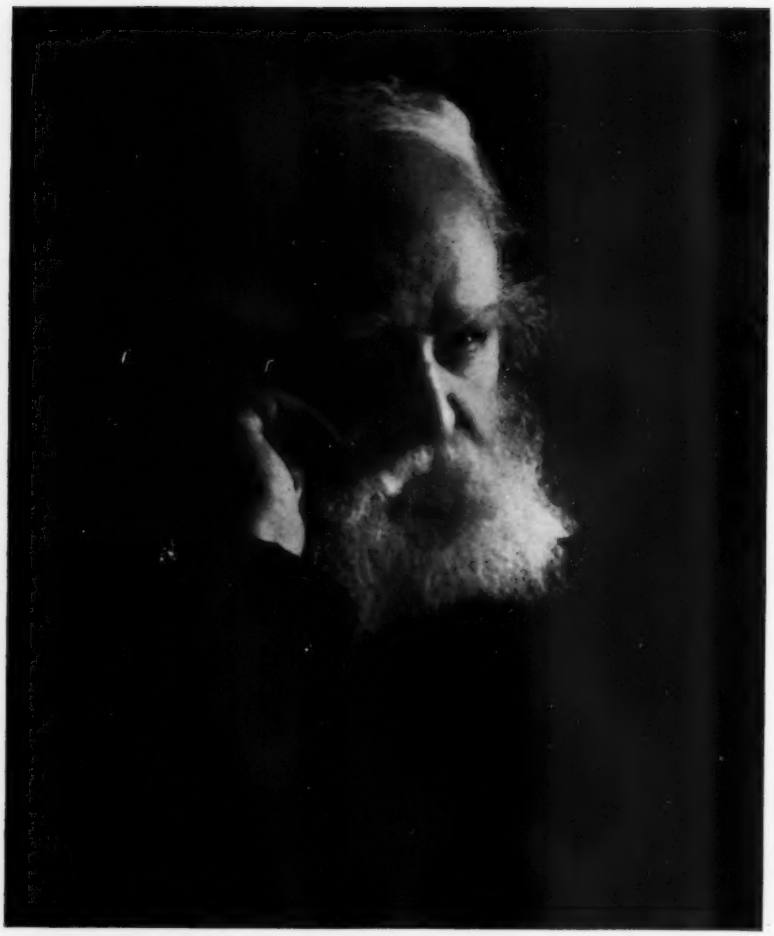
The plates were taken by Messrs. Parkhurst and Jordan, mostly with an exposure of one hour, and show stars to the sixteenth photographic magnitude, approximately. The price, intended merely to cover the cost, will probably be 25 cents for each print.

Address the SECRETARY OF THE YERKES OBSERVATORY, Williams Bay, Wis.

NOTICE OF GENERAL INDEX

A general index to the first twenty-five volumes of the *Astrophysical Journal*, covering the period of twelve and one-half years from January 1895 to June 1907, has been prepared by Mr. S. B. Barrett, librarian of the Yerkes Observatory. It is arranged both by authors and by subjects, and forms a book of 136 pages, bound in paper, conforming in size and style to the regular volume indices of the *Journal*.

It may be obtained from the University of Chicago Press, at a price of $1.50, postpaid. European subscriptions will be filled through Messrs. William Wesley & Son, 28 Essex Street, Strand, London, England, and future foreign orders should be sent to this address (price 6*s*. 6*d*.). Free copies cannot be supplied, either for periodicals received in exchange for the *Astrophysical Journal*, or otherwise.



JULES CÉSAR JANSSEN